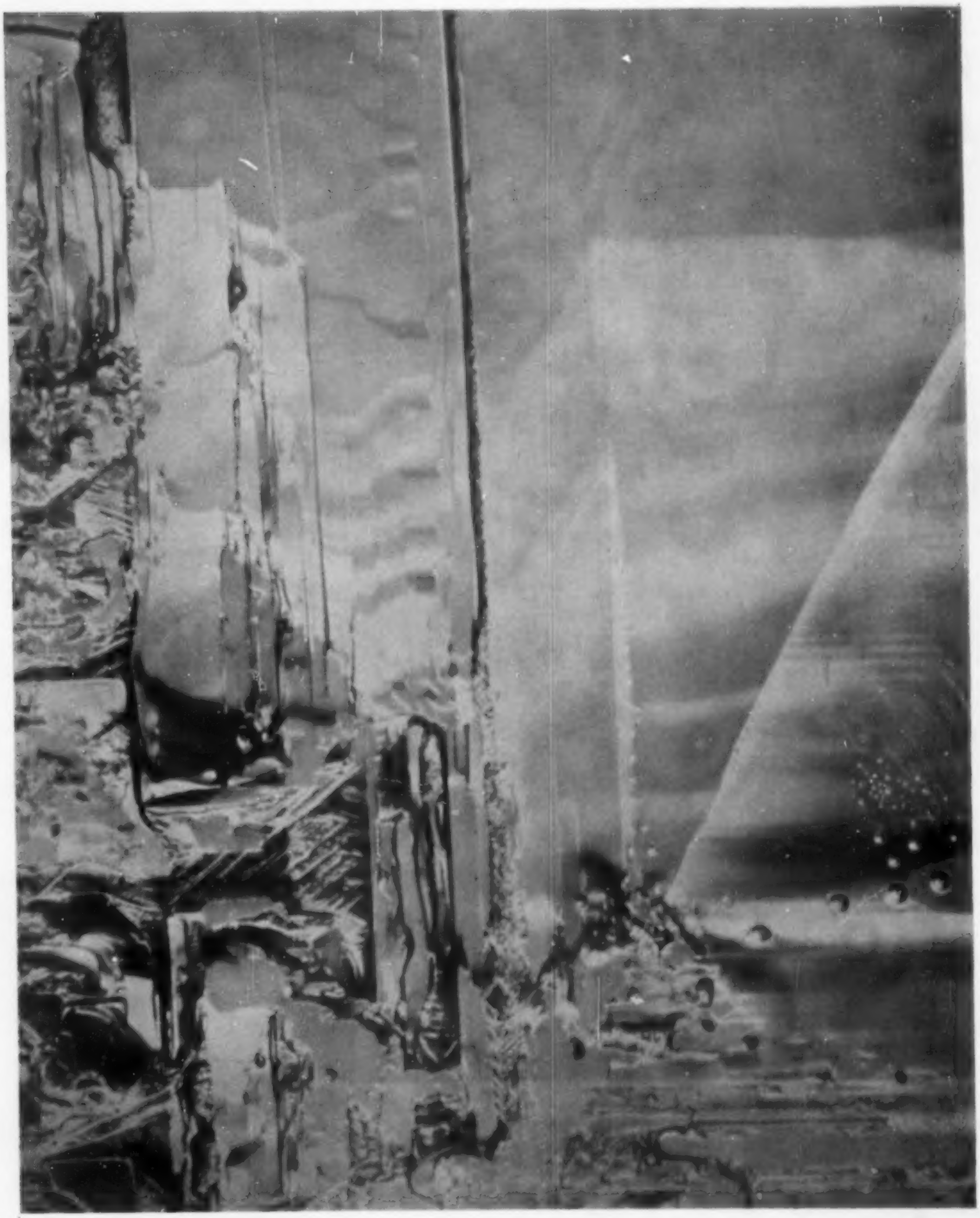
Metal Progress

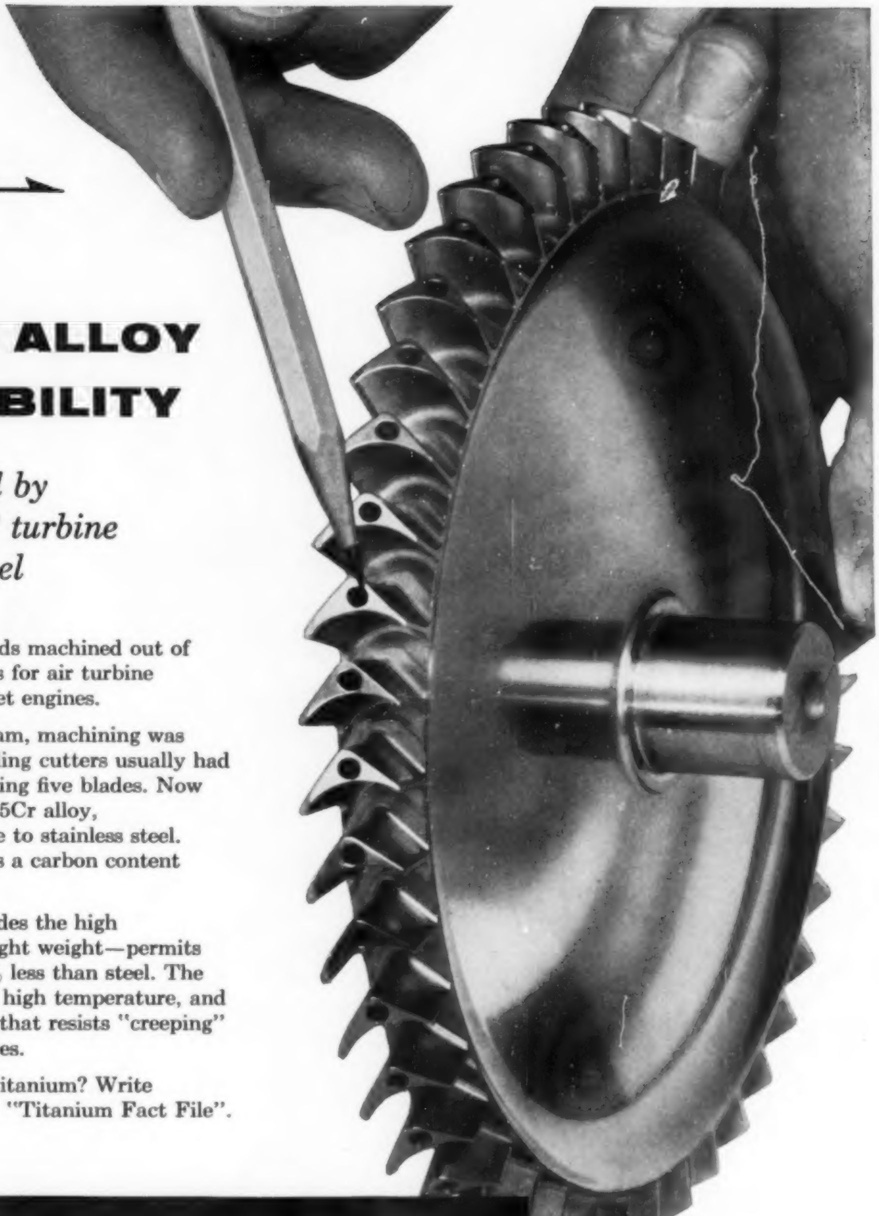


August 1957

Progress with
TITANIUM

TITANIUM ALLOY MACHINABILITY

demonstrated by Bendix turbine starter wheel*



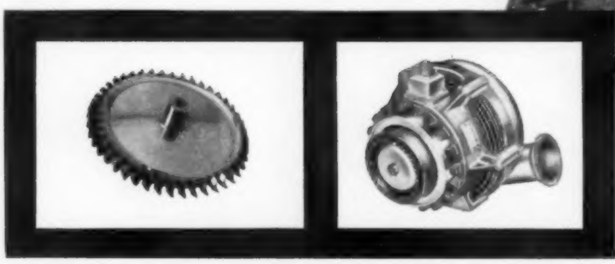
This wheel is one of hundreds machined out of solid titanium alloy forgings for air turbine starters, used to crank up jet engines.

At the start of this program, machining was extremely difficult, and milling cutters usually had to be replaced after machining five blades. Now with low-carbon MST 3A1-5Cr alloy, machinability is comparable to stainless steel. (Mallory-Sharon guarantees a carbon content of 0.1% maximum.)

Only titanium alloy provides the high strength required at such light weight—permits Bendix to cut weight—44% less than steel. The alloy maintains strength at high temperature, and meets the need for a metal that resists "creeping" under great centrifugal forces.

May we help *you* apply titanium? Write Dept. R-8, for new booklet "Titanium Fact File".

**Registered trade mark*



Air Turbine Starter *made by Utica Division of Bendix Aviation Corporation is relatively light in weight, small in overall dimensions.*

MALLORY Ti SHARON

MALLORY-SHARON TITANIUM CORPORATION · NILES, OHIO

Producers of titanium and titanium alloy sheet, strip, plate, rod, bar, billets

Metal Progress

Volume 72, No. 2
August . . . 1957

The cool-looking micro on the cover was made by D. M. Cheney of Battelle Memorial Institute and was exhibited at the 1956 A.S.M. Metallographic Exhibit. It shows the surface of an arc-cast ingot of 90% uranium, 10% silicon alloy, made with no surface preparation. Oblique illumination with off-centered lighting. 100×; enlarged 2×.

Engineering Articles

Table of Contents Continued on Page 3

Metal Progress is published monthly by the American Society for Metals. Publication office, Mt. Morris, Ill. Editorial, executive and advertising offices, 7301 Euclid Ave., Cleveland 3, Ohio. Subscription $7.50 a year in U.S. and Canada; foreign $10.50. Single copies $1.50; special issues $3.00 . . . The A.S.M. is not responsible for statements or opinions in this publication.

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**The coding symbols refer to the ASM-SLA Metallurgical Literature Classification, Revised Edition, 1957*

As I was saying...

It was the closing day of the National Metal Congress and Exposition in Cleveland in 1949 when President-Elect Arthur Focke came into my office at the Public Auditorium to discuss the if, when and how of A.S.M. activities for the coming year. At that time I suggested a plan to have a World Metallurgical Congress in connection with the National Metal Congress. As the plan unfolded President Art became so enthusiastic that in a few weeks we were both in the office of Paul Hoffmann, then Chief of E.C.A. (Economic Cooperation Administration) to present the plan to him.

The idea met with Dr. Hoffmann's instantaneous approval because, as he stated, it was the first time that scientists and engineers from *all* E.C.A. countries would come to America at the same time and on the same mission, and this plan would permit the metallurgists and the metal scientists not only to exchange ideas and experiences with American counterparts but also would permit European nations to become better acquainted among themselves.

So thus was the First World Metallurgical Congress born — and it became a successful reality at Detroit in October of 1951.

Now, some six years later, the Second World Metallurgical Congress will be held in Chicago, Nov. 2 to 8, 1957. This event has had our constant thought and careful planning so that it may equal or perhaps exceed the fine results of its predecessor. More than 600 overseas metal scientists and engineers have indicated their desire to participate, and 352 have so far sent in their final application papers to become "Conferees." Thos. Cook & Sons will handle the travel and hotel arrangements for eight different two-week tour groups preceding the opening of the Congress in Chicago on Saturday, Nov, 2. Each conferee has selected one of the eight groups with which he will make the plant tours. Then all will be housed in Chicago's Sherman Hotel where many sessions of the Congress will be held.

A source of tremendous satisfaction has been the ready response of more than 70 metal firms to our request to receive the overseas conferees. Not only have they opened the gates but many have invited the visitors to luncheons and dinners and meetings.

The opening event will be held in New York, where the overseas visitors will assemble on Oct. 19. A "Welcome to America" luncheon will be held at the Waldorf-Astoria on Monday, Oct. 21, when the A.S.M. and Second World Metallurgical Congress officials, the top city and state officials, and the captains of the metal industry will bid the overseas conferees welcome.

One week later the entire entourage will be in Cleveland, and Mill and I will have the opportunity to entertain them at Sunnimoor Farm with "Life in Early America", as it was our happy privilege to entertain the members of the First World Metallurgical Congress.

The "Welcome to Chicago" meeting will be at the Sherman Hotel, Sunday afternoon, Nov. 3 at 3:00 p.m., and after that the American counterparts will have a "Get Acquainted" meeting with the overseas conferees.

Sunday evening, Nov. 3, at 8:00 p.m. at the Palmer House the first session of the Second World Metallurgical Congress will be held, with international speakers presenting "The Future of this Wonderful World of Metals".

Then the Congress (with some 80 different sessions); the Exposition, largest in history; the luncheons; the dinners and banquets; and then the final event of the National Metal Congress and the Second World Metallurgical Congress, a banquet attended by all the overseas conferees, their American counterparts, Society officials, members and exhibitors. The banquet theme will be "America and the A.S.M. Bid you Farewell".

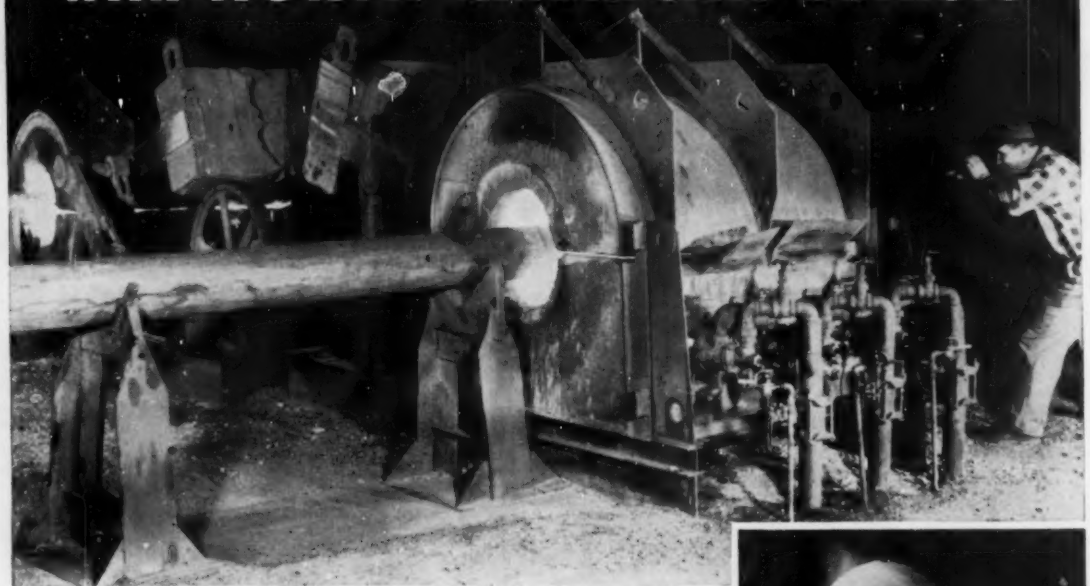
The next morning the conferees leave for New York or other destinations. We are confident that, as in '51, the A.S.M., the American Counterparts and the Overseas Conferees will consider this experience one of their richest possessions. To mingle with others having the same life interest, the same hopes (for peace); the same desires, the same longing for firm and precious friendships, will give everybody the feeling that after all we are all alike; we all love life, liberty and happiness.

Cordially yours,

Bill

W. H. Eisenman, *Secretary*
American Society for Metals

Huge Crankshafts GET HOT IN A HURRY with NORTH AMERICAN Burners



High speed heating, such as usually applied to small parts in mass production, is used by **Erie Forge & Steel Corporation** for heating huge locomotive crankshafts for die press forging . . . convincing evidence of the efficiency of North American Burners and Blowers.

Amazingly, **#6 oil** is used to fire these compact barrel-type furnaces. North American Blowers and Series 212 Burners provide thorough atomization for fast heat release.

8⅞" billets are heated from 1100 F to 2350 F in a day-long **average** time of 36.9 minutes. The result—superior quality metal. Average oil consumption is 32 gallons per ton of steel. It will pay you to look into the results you can expect by installing North American for high speed heat release.

Large photo shows 8⅞" billets in 2 of 8 small (36" I.D.) furnaces. Note Burners in right foreground.

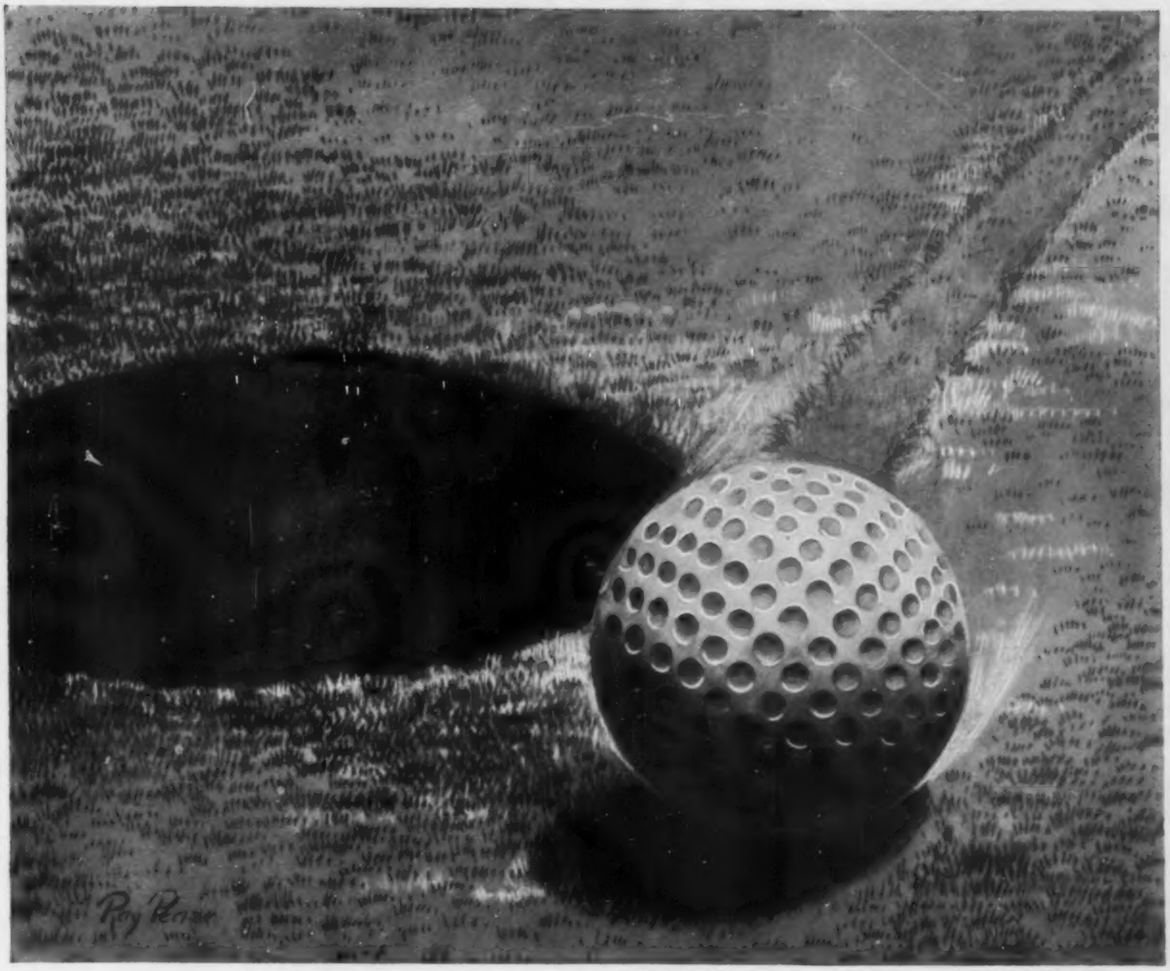
Small photo is a close-up view showing burner tiles and flames whipping around a partially forged 10" crankshaft in a large furnace.

For detailed engineering information, consult your nearby North American combustion specialist. For equipment information, write for bulletin.

212

NORTH AMERICAN COMBUSTION Since 1917

The NORTH AMERICAN Manufacturing Co.
Combustion Engineers
Cleveland 5, Ohio



This modern boat trailer uses Youngstown Pipe for strong all-welded steel construction of its boat cradle and main trailer chassis.

YOUNGSTOWN CONTINUOUS WELD PIPE

. . . provides extra-strength chassis for "Texan" boat trailers

Here's an unusual application for steel pipe. "Texan" Boat Trailers, produced by the Cunningham Trailer Works of Lubbock, Texas, are fabricated from Youngstown Pipe to provide users maximum cargo protection as well as greatest ease during loading, unloading and while making the haul.

In line with Cunningham's policy of using only the highest quality raw materials, they wisely specify Youngstown Continuous Weld Pipe for fabrication of both the boat cradle and main trailer chassis. This gives Texan boat trailers a sturdy welded steel construction able to withstand the most rugged use—on or off the highway. Why not use Youngstown Pipe structurally to build strength and quality into your products?

Your local Youngstown Distributor is the man to call when you want quality pipe—day or night. He has a complete stock and his on-the-spot fast delivery will help keep your operations humming along at top speed. Why not call him today?

Next time you need pipe—for any purpose—specify Youngstown and secure these 7 Points of uniform goodness

- uniform ductility
- uniform lengths
- uniform threading
- uniform weldability
- uniform wall thickness and size
- uniform strength and toughness
- uniform roundness and straightness

QUALITY YOUNGSTOWN SERVICE

THE YOUNGSTOWN SHEET AND TUBE COMPANY
Manufacturers of Carbon, Alloy and Yoloy Steel
General Offices - Youngstown 1, Ohio
District Sales Offices in Principal Cities

Why **DYNALOG*** *design is out front of all electronic potentiometers . . .*

IT'S THE MAINTENANCE MAN'S DREAM!

Advance features to improve control of temperature, pressure, flow . . .

1. No periodic maintenance
2. No dry cell—no standardizing
3. No high-speed moving parts
4. No slidewire or galvanometer
5. *Stepless*, continuous balancing
6. Adaptable to narrow spans

Yes, you can actually eliminate the continual inspection and maintenance usually required by balancing-type process control instruments! DYNALOG Electronic Instruments provide *uninterrupted* evaluation of many process variables . . . *sustained* high accuracy. DYNALOGS are inherently free from "drift" or mechanical problems . . . have no dry cells to standardize or replace . . . require no lubrication or alignment. They're dustproof, vibration-proof, foolproof.

This troublefree performance is a direct result of the unique DYNALOG Design. No troublesome slidewire and balancing motor . . . just a simple, variable radio-type capacitor and positive magnetic drive. The friction-free system responds instantly . . . gives unmatched smoothness of balancing . . . years of faultless service. DYNALOG Instruments are used with any primary element — resistance, voltage, capacity, inductive — wherever there's a precise control or recording job to be done. For the complete story, write for Bulletin 20-10. **The Foxboro Company, 528 Neponset Ave., Foxboro, Mass., U.S.A.**

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DYNALOG
ELECTRONIC INSTRUMENTS

*Reg. U. S. Pat. Off.

SPECIAL REPORTS ON FINISHING NON-FERROUS METALS

NUMBER III—Lustrous, Corrosion-Resistant Finishing with Chemical Polishing Iridite

WHAT IS IRIDITE®?

Briefly, Iridite is the tradename for a specialized line of chromate conversion finishes. They are generally applied by dip, some by brush or spray, at or near room temperature, with automatic equipment or manual finishing facilities. During application, a chemical reaction occurs that produces a thin (.00002" max.) gel-like, complex chromate film of a non-porous nature on the surface of the metal. This film is an integral part of the metal itself, thus cannot flake, chip or peel. No special equipment, exhaust systems or specially trained personnel are required.

Chromate conversion coatings are widely accepted throughout industry as an economical means of providing corrosion protection, a good base for paint and decorative finishes for non-ferrous metals. Certain of these coatings also possess chemical polishing abilities that have luster-producing, as well as corrosion-inhibiting, effects on zinc and cadmium plate, zinc die castings and copper alloys. However, continued developments in this field have been so rapid that many manufacturers may not be completely aware of the breadth of application of this type of finish. Hence, this discussion of the many ways in which this chemical polishing characteristic can be used in final finishing or pre-plating treatments to produce a lustrous appearance with distinct display and sales appeal and appreciable savings in cost. Report I on decorative, corrosion-resistant finishes and Report II on paint base corrosion-resistant finishes are available on request.

The degree of luster possible on a surface is a function of the degree to which the surface can be smoothed. Leveling to provide a smooth surface can be achieved by mechanical or chemical means, or a combination of these, depending upon the luster desired and the original condition of the metal. Chemical polishing effectively imparts luster otherwise difficult and costly to obtain. For this reason, it is often used to supplement or entirely replace mechanical polishing, depending upon the application and the original condition of the metal. Chemical polishing has the additional advantage of providing overall treatment of the submerged part. It reaches into even the deepest corners and recesses that are otherwise inaccessible. Certain of the Iridites are specifically designed to perform this chemical polishing operation. Also, they provide corrosion protection as do all Iridites, thus may be used as a final finish or a pre-plating polish.

If Iridite is to be used as a final finish, in contrast to pre-plating treatment, the chromate conversion coating generated is allowed to remain, providing good corrosion resistance. Color inherent in these Iridite films ranges from a yellow cast to yellow iridescent. These coatings may be used without further treatment where this color is acceptable and good corrosion resistance is desired. Further, these basic coatings can be tinted by dyeing. Among the dye tints available are shades of red, yellow, blue and green. If desirable, the basic coatings can also be modified by a bleach dip leaving a clear bright or blue iridescent finish. In all cases bleaching reduces corrosion resistance.

As examples of this type of final finishing, Iridites #4-73 and #4-75 (Cast-Zinc-Brite) make possible for the first time, lustrous chemical polishing of the as-cast surface of zinc die castings. Thus, in many cases, sizeable savings in finishing cost are realized by elimination of plating costs. This economical method can be used on tools, appliance parts, toy pistols, locks and many other small castings. Another example is the treatment of copper and brass parts, such as welding tips, to eliminate buffing and provide additional corrosion resistance. In many cases, handling costs are reduced appreciably by replacing piece-part handling with bulk processing. Still another example of the use of this chemical polishing and protective quality of Iridite is a simple system of zinc plate, Iridite and clear lacquer instead of more costly electroplated finishes. Typical of this type of lustrous finish are builders hardware and wire goods.

As a pre-plating treatment, in contrast to final finishes, Iridite can be used to chemically polish zinc die castings or copper prior to plating. In such cases, Iridite should be applied as an in-process step, so that the protective film is removed before the plating cycle. The savings in handling, material and labor costs are obvious. This process has made it practical to plate chrome directly over copper on steel, conserving nickel, yet producing a lustrous chrome finish. Used after stripping faulty plate in reprocessing zinc die castings, Iridite restores luster to the casting, thus making possible replating without blistering.

Other Iridite finishes are available to produce maximum corrosion resistance, a wide variety of decorative finishes and excellent bases for paint on all commercial forms of the more commonly used non-ferrous metals. As a final finish, appearance ranges from clear bright to olive drab and brown and many films can be bleached or dyed. As a paint base Iridite provides excellent initial and retentive paint adhesion and a self-healing property which protects bare metal if exposed by scratching. Iridites have low electrical resistance. Some can be soldered and welded. The Iridite film itself does not affect the dimensional stability of close tolerance parts.

Iridites are widely approved under both Armed Services and industrial specifications because of their top performance, low cost and savings of materials and equipment.

You can see then, that with the many factors to be considered, selection of the Iridite best suited to your product demands the services of a specialist. That's why Allied maintains a staff of competent Field Engineers—to help you select the Iridite to make your installation most efficient in improving the quality of your product. You'll find your Allied Field Engineer listed under "Plating Supplies" in your classified telephone book. Or, write direct and tell us your problem. Complete literature and data, as well as sample part processing, is available. Allied Research Products, Inc., 4004-06 East Monument Street, Baltimore 5, Maryland.

Largest bronze centrifugal casting ever made, 54¾" O.D. x 49½" I.D. x 346½" long. Charge weight—72,300 pounds.

At Sandusky,

GIANTS ARE ROUTINE...

Small wonder. We serve giant industries . . . paper-making, shipbuilding, metalworking, atomic energy, petro-chemical, and others . . . with centrifugally cast cylinders and tubular parts, many of which can't be made by any other process to the exacting standards required.

It's the 47 years of specialized experience coupled with unequalled manufacturing facilities . . . that makes it routine for our engineers and production teams to cast and machine *cylinders from 7" to 54" O.D. and up to 33 feet in length . . .* in a wide range of alloys meeting special performance requirements.

Do you need a giant cylindrical form . . . or a small one . . . machined to exact working dimensions? Send us your specifications; we'll reply promptly.

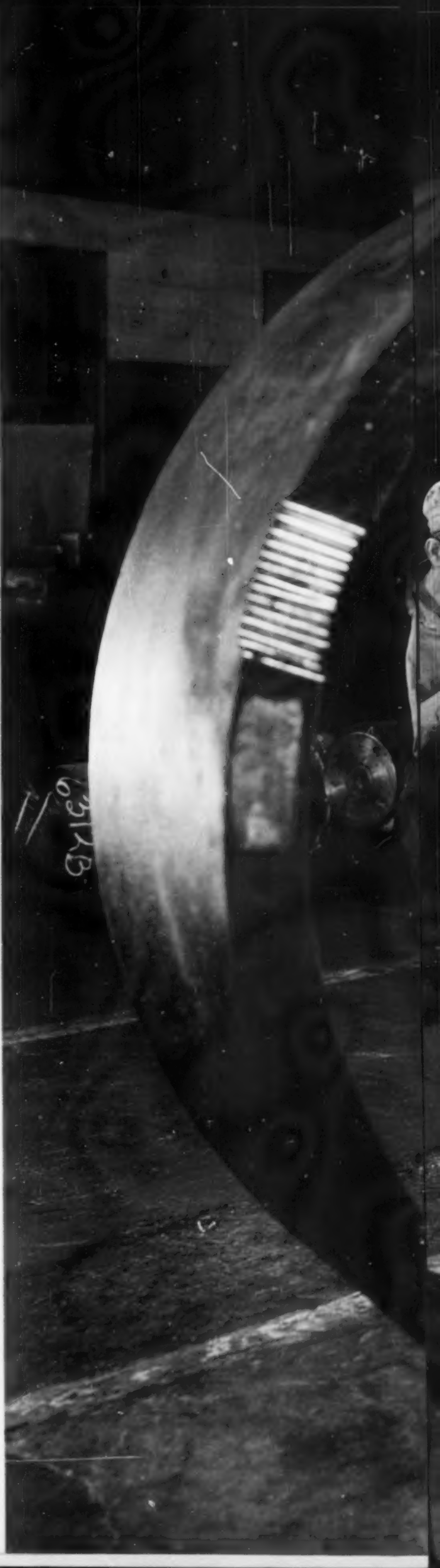
Sandusky Centrifugal Castings offer you 4 important advantages:

1. ***SUPERIOR MECHANICAL PROPERTIES*** —to meet exacting design requirements
2. ***UNIFORM SOUNDNESS***—free from harmful inclusions and porosity
3. ***HIGHEST QUALITY***—to insure long, dependable, trouble-free service
4. ***JOB-READY CASTINGS***—machined to your exact specifications, eliminate extra costs from rejects, down-time, loss of production

CENTRIFUGAL CASTINGS

Sandusky Foundry & Machine Company

SANDUSKY, OHIO • *Stainless, Carbon, Low Alloy Steels—Full Range Copper-Base, Nickel-Base Alloys*



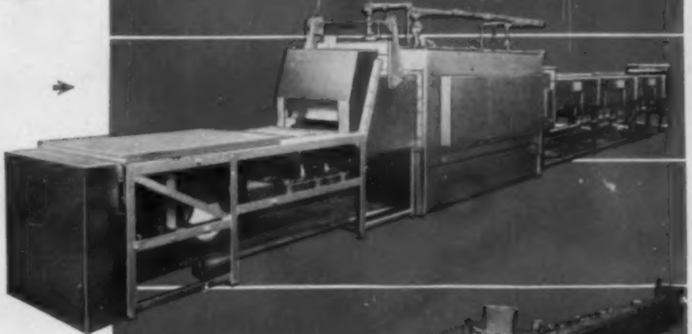
Look to Lindberg for Sintering Furnaces

For sintering furnaces, just as in all types of industrial heating equipment, you can depend on Lindberg's ability to supply exactly the right equipment for your needs. Here are some typical Lindberg sintering furnaces:

This Hand Pusher Batch Type Furnace

is used for small production lots and experimental sintering. It is an all-purpose unit for operation from 1300°F to 2500°F. Made in various sizes for sintering from 25 to 300 pounds per hour.

This Mesh Belt Continuous Type Furnace



is a popular sintering furnace for small light parts in copper, bronze, brass or steel with a temperature range from 1300°F. to 2100°F. It can be used for low temperature silver brazing, bright annealing, as well as sintering of powder metals. Production ranges up to 500 pounds per hour.

This Roller Hearth Continuous Type Furnace

is especially designed to handle heavier loads up to 2200 pounds per hour. It has an effective temperature range from 1300°F. to 2100°F. It can be used for bright annealing, low temperature silver brazing as well as sintering of powder metals.

Atmosphere Generators

To obtain the best work from any sintering furnaces, the proper atmosphere is required. The atmosphere generators described here provide the proper atmospheres recommended for use with Lindberg Sintering Furnaces.

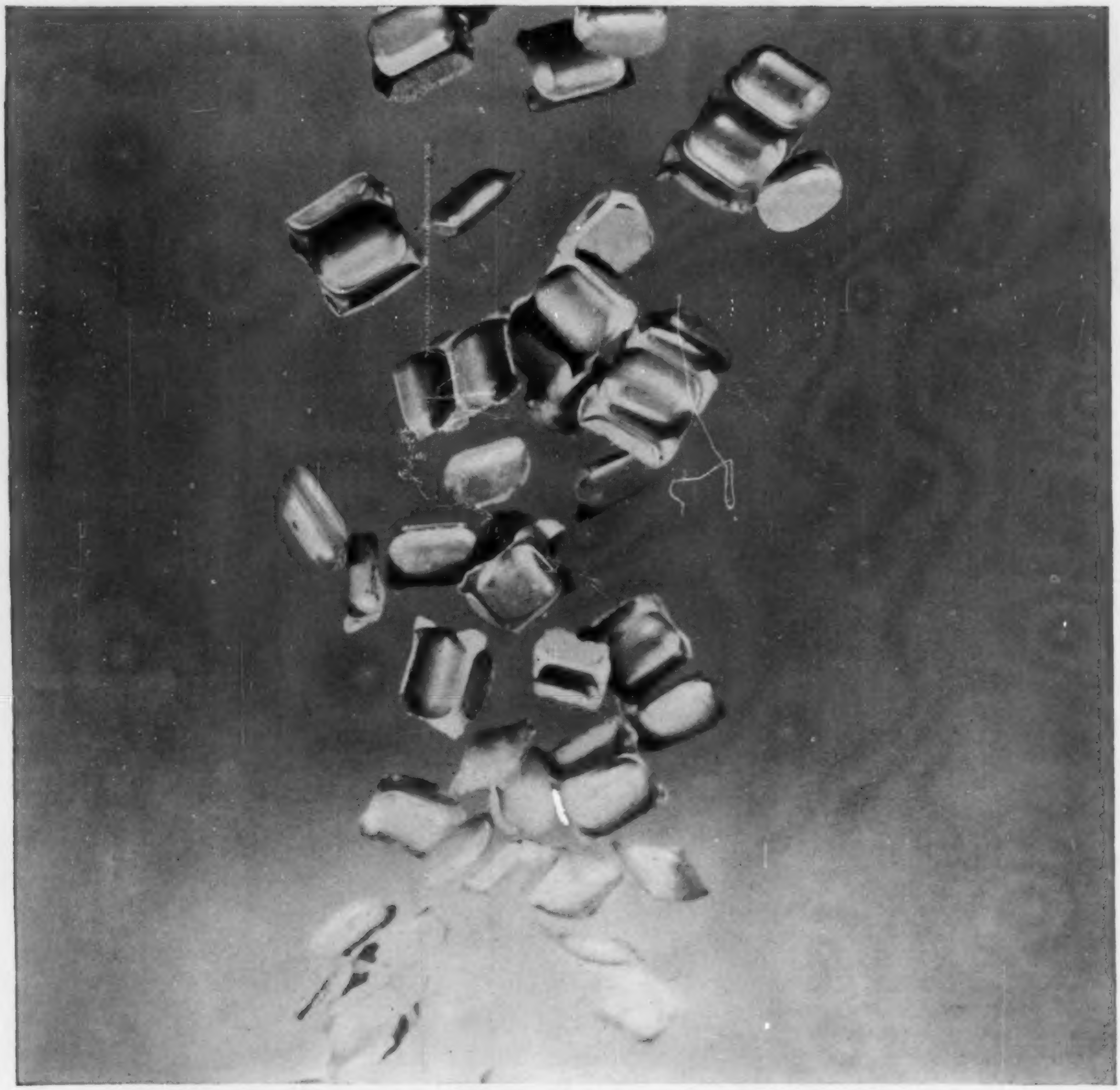
1. The HYEX Generator produces atmosphere composed of approximately 4% carbon dioxide—15% hydrogen—12% carbon monoxide and 69% nitrogen.
2. The HYEN Generator produces a neutral atmosphere composed of approximately 21% carbon monoxide—40% hydrogen—38% nitrogen and 1% methane.
3. The HYAM Generator produces atmosphere composed of approximately 75% hydrogen and 25% nitrogen.

If you have a sintering or brazing problem why not talk it over with Lindberg. Just get in touch with your nearest Lindberg Field Representative or write us direct.

LINDBERG ENGINEERING COMPANY

2448 W. HUBBARD ST., CHICAGO 12, ILL.

Los Angeles Plant: 11937 S. Regentview Ave., at Downey, Cal.



TITANIUM BRIQUETTES...

IN PRODUCING SUPER ALLOYS and stainless steel, you'll get higher titanium residual with reduced additions of TAM titanium briquettes...plus efficient deoxidation and stabilization. The convenient uniform size and shape of the briquettes make them easy to handle. They offer higher efficiency—dissolve readily and produce a cleaner metal with low aluminum and silicon and non-metallic inclusions. Titanium powder is firmly compressed into TAM briquettes...*which do not crumble during handling.* Shipped in metal drums. For prices and delivery data, contact our New York City office.

TAM PRODUCTS
Registered U. S. Pat. Off.

TITANIUM ALLOY MFG. DIVISION
NATIONAL LEAD COMPANY
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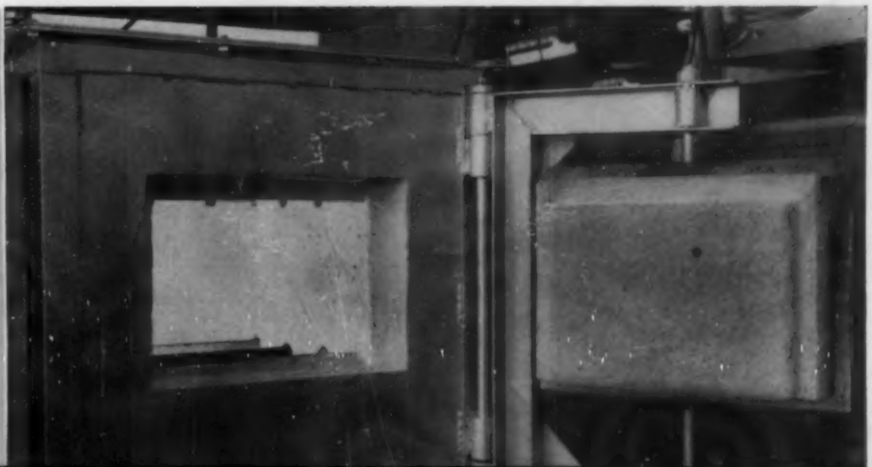
General Offices, Works and Research Laboratories:
Niagara Falls, New York



LINED WITH ALUNDUM 33-I CASTABLE, this furnace has been used for almost a year as a periodic furnace for high-temperature laboratory test work. During this time the door was opened and closed over a thousand times with the furnace at temperature. Even after this rugged service, the ALUNDUM Castable lining shows hardly any signs of wear.

LINED WITH A COMPETITIVE HIGH GRADE INSULATING BRICK, this similar furnace was used in the same service for an equal length of time. Under equally severe thermal shock conditions the lining cracked and spalled and this furnace must be rebuilt.

You get higher temperature protection with ALUNDUM* castables

Up to 3300° F!

ALUNDUM 33-I Insulating Castable is made up primarily of countless tiny, pure aluminum oxide bubbles. Forming a network of air spaces it provides excellent insulation, even at the highest commercial temperatures.

ALUNDUM 33-HD Heavy Duty Castable is chiefly composed of dense grains of pure aluminum oxide. It is recommended for forming dense monolithic surfaces in constructing many types of furnaces where high temperature conditions are more severe.

Both ALUNDUM 33-I and 33-HD Castables protect at temperatures up to 3300° F and are very easy to mix and use. You can cast simple or complex shapes with them quickly and inexpensively for many installations and replace more expensive pre-fired shapes.

See your Norton Representative for more facts on how these new Castables can provide long, trouble-free service that saves you time and money. Ask him for the folder *Two New Norton Castables,* or write for your free copy to NORTON COMPANY, Refractories Division, 327 New Bond Street, Worcester 6, Mass.

*Trade-Mark Reg. U. S. Pat. Off. and Foreign Countries

NORTON

REFRACTORIES

Engineered ... R ... Prescribed

Making better products ... to make your products better

NORTON PRODUCTS:
Refractories • Abrasives
Grinding Wheels • Grinding Machines
BEHR-MANNING DIVISION PRODUCTS:
Coated Abrasives • Sharpening Stones
Behr-cat Tapes

Brings more uniformity to heat-treating

MORE uniform quench
MORE uniform heat
MORE uniform case depth

All these "plusses" are yours with the new Eclipse Clean-Line furnace because: (1) atmosphere and temperature are distributed with complete uniformity during heating — there's no stratification — and (2) even tightly packed loads of the smallest parts are quenched uniformly in the oil jet-agitated tank served by the high-capacity pump. The Clean-Line furnace, rated to heat-treat 400 lb of work in one hour, and with quench capacity for 700 lb per load, is designed for fully automatic clean hardening, carbonitriding, carburizing, carbon restoring, or annealing. Standard Clean-Line furnaces are designed for operation at temperatures up to 1850° F.

Complete control of all heat-treat operations is right at your fingertips. You can select an air or oil quench, for example, just by flicking a switch on the control panel. Heating cycle, high oil pump circulation, and quenching cycle for a particular workpiece can all be controlled precisely and automatically by three separate timers on the control panel. All these features add up to better quality — every piece in every batch.

WRITE for bulletin and data sheets describing the Clean-Line system that includes endothermic generators, automatic washers, and tempering units.

Eclipse®

APPLICATION and EQUIPMENT new products

Atmosphere Generator

A new line of controlled-atmosphere generators with standard capacities of 750, 1000, and 1250 cu. ft. per hour has been announced by Eclipse Fuel Engineering Co. The generators produce an endothermic atmosphere with a low dew point and a gas analysis that is approximately 40% hydrogen, 20% carbon monoxide, balance nitro-

gen. Gas and air are measured by separate flowscopes and are mixed in an air-gas mixer equipped with a manual ratio adjustment. The air-gas mixture is pumped into the Inconel retort. The retort heating chamber is lined with insulating firebrick. Operating temperature of the retort heating chamber is 1800° F. Here the air-gas mixture forms the endothermic atmosphere and is piped through a cooler.

For further information circle No. 323 on literature request card, page 48-B.

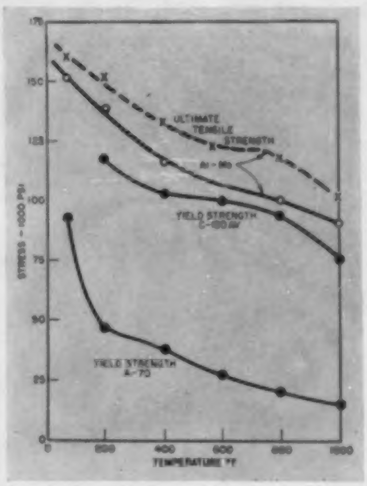
Nickel-Alloy Cladding

A new method of applying nickel-alloy coatings has been announced by the Tube Reducing Corp. It may be applied to all shapes and sizes. After application the Niphos coating is heated in a reducing atmosphere to provide a tightly-adhering nickel-alloy cladding which will not peel or flake when subjected to a 180° bend. The clad coating can be applied locally to areas which are to be joined by brazing; then the brazing operation is completed by merely placing the coated areas in contact and heating them. Average coatings are about 0.001 in. thick, but coatings up to 0.025 in. can be obtained in one application. This thickness can be increased still further by repeated applications. The Niphos coatings can prevent scaling of the base metal at temperatures as high as 1150° F.

For further information circle No. 324 on literature request card, page 48-B.

Titanium Alloy

A new titanium alloy with high strength at room and elevated temperatures has been announced by Rem-Cru Titanium, Inc. The alloy, know as Rem-Cru C-130AMo, has a nominal composition of 6.50% aluminum and 3.75% molybdenum. The aluminum-molybdenum-titanium alloy offers improved elevated temperature strength. The accompanying illustration shows the comparative short time yield strength and creep results for the new alloy compared to present grades. It has good time-temperature-stress stability and deep harden-



ability and good heat treated properties. Samples of the new alloy exposed to high stress in the 600 to 1000° F. temperature range show undiminished strength and good ductility in subsequent room temperature tensile tests.

For further information circle No. 325 on literature request card, page 48-B.

Metal Crystals

Flow Corp. has announced the availability of metal single crystals and polycrystals in most metals. A broad range of metal purity, crystal

orientation, and overall size is available. The surface may be as-grown, etched, or electropolished.

For further information circle No. 326 on literature request card, page 48-B.

Thermocouple Vacuum Gage

A single-station, panel-mounted thermocouple vacuum gage has been announced by the Rochester Div. of Consolidated Electrodynamics Corp. This gage operates on two size "D" flashlight batteries contained within its housing. Two terminals are provided on the bottom of the instrument for connection of an external battery power supply. The range of the gage from 0 to 1000 microns Hg of dry air pressure is covered on one nonlinear scale, with 5 microns the smallest indicated marking. The pressure range from 0 to 60 microns Hg extends over more than half of the entire scale.

For further information circle No. 327 on literature request card, page 48-B.

Corrosion Inhibitor

A new corrosion inhibitor for use in sulfuric, sulfamic and phosphoric acids has been announced by the Chemical Div., Armour and Co. Inhibitor 2508, an aliphatic derivative, is in liquid form and can be used at rates as low as 100 to 500 ppm. Mild steel in 15% sulphuric acid at 200° F. has a corrosion rate over 2.5 lb. per sq. ft. per day, compared to less than

0.03 lb. per sq. ft. per day in an inhibited acid.

For further information circle No. 328 on literature request card, page 48-B.

Tube Forming

An automatic double-end tube forming machine has been announced by Vaill Engineering Co. The machine is hydraulically operated. The tube is transferred from a gravity magazine to the work position, clamped, formed and ejected automatically. This machine can be arranged for

double operation work through the use of double stroking work slides with the indexing of the forming tools between each stroke. This machine can be tooled to expand and reduce in diameter, to bead, to flare and flange the ends of tubing in various sizes and lengths. Production rates of up to 1500 pieces per hour can be achieved.

For further information circle No. 329 on literature request card, page 48-B.

Portable Oven

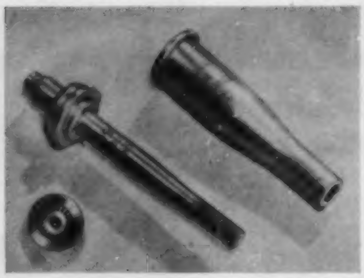
A new bench oven with drawers has been announced by Grieve-Hendry Co. This oven has 8 drawers to permit processing of different materials at the same time and to permit filling of drawers at intervals to keep pro-

duction flowing. Temperature is adjustable to 325° F. and controlled by thermostat. It weighs 138 lb. and plugs into 110 volt a.c. outlet. Forced air circulation is by an electric-motor driven fan. Outside dimensions are 30 by 25 by 24 in. Drawers of expanded metal are 2 by 11½ by 23 in.

For further information circle No. 330 on literature request card, page 48-B.

Flame-Cutting

New two-piece nozzles which increase flame-cutting speeds have been

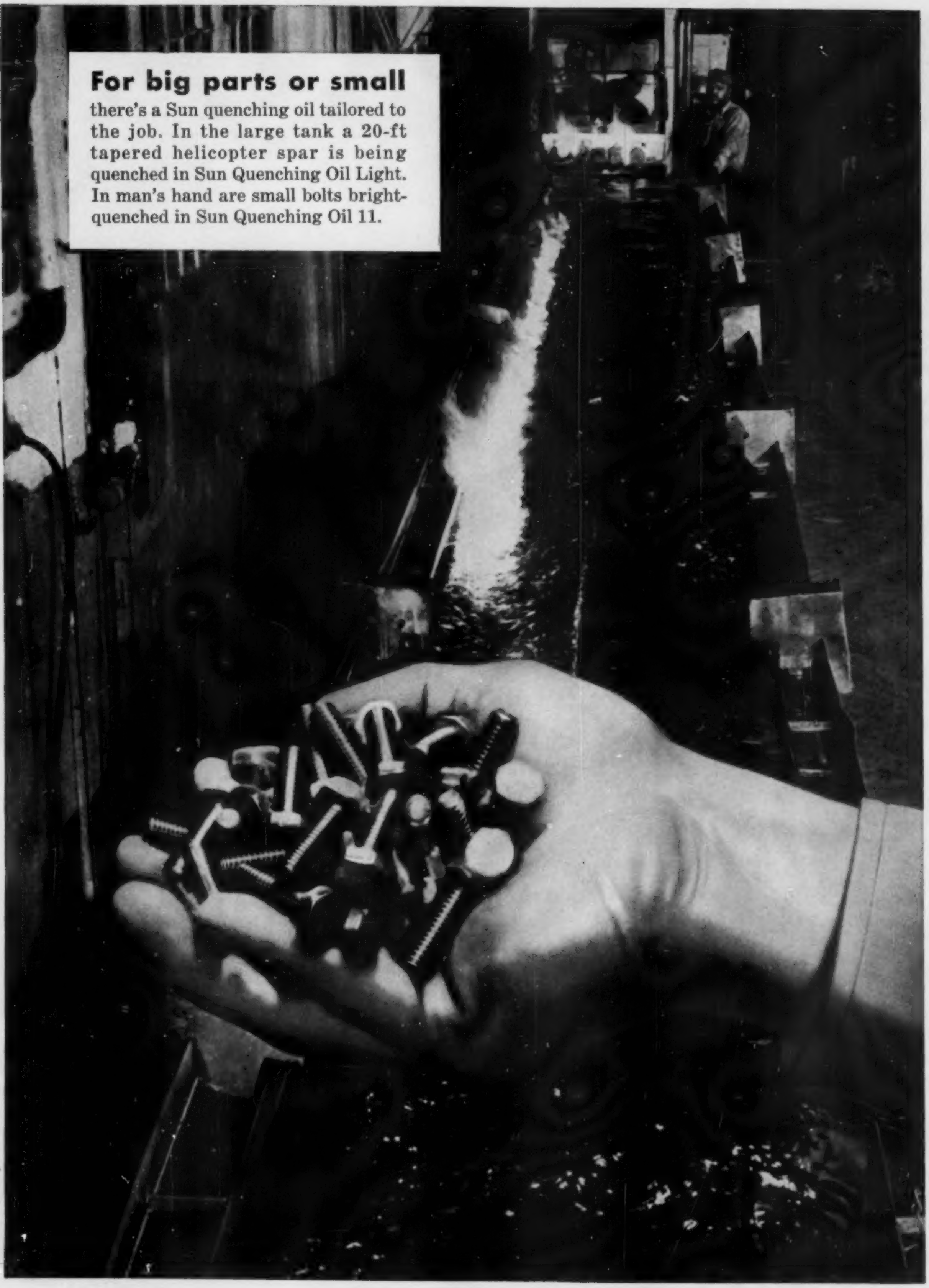


announced by Linde Co. Designed for flame-cutting with oxygen and fuel gases, each of the two-piece nozzles has from 12 to 20 extremely small outlets for preheat gases. This feature increases the rate of heat transfer and produces a nearly solid ring of preheat flames. A divergent bore design boosts cutting speed to 1200 ft. per second. Each two-piece nozzle consists of a brass internal section with finely grooved slots for preheat gases, and a heat-resistant copper cover.

For further information circle No. 331 on literature request card, page 48-B.

Cold Cleaner

Octagon Process, Inc., has announced a new general purpose cold solvent emulsion metal cleaner for fer-


For big parts or small
there's a Sun quenching oil tailored to the job. In the large tank a 20-ft tapered helicopter spar is being quenched in Sun Quenching Oil Light. In man's hand are small bolts bright-quenched in Sun Quenching Oil 11.

rous and nonferrous parts. It will remove lubricating oil, grease, buffing compounds and general soil found in normal metal working operations. The cleaner is used at room temperature. Parts are dipped or soaked in the solvent and are next rinsed in water, warm if possible, or pressure sprayed.

For further information circle No. 332 on literature request card, page 48-B.

Stress-Rupture and Creep Testing

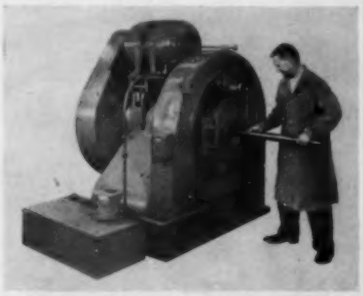
A new combination stress-rupture and creep testing machine has been announced by the Tinius Olsen Testing Machine Co. It is air operated. The applied load is indicated on a large dial at the top of the machine. If desired, the amount of elongation

under a prevailing load can be plotted automatically on a built-in electronic recorder. It is available in 12,000 lb. or 20,000 lb. capacities. Selectable loads can be applied and maintained for any desired period of time from minutes to years. Separate temperature controls enable the operator to select any furnace testing temperature up to the limit of the unit—1800 or 2000° F.

For further information circle No. 333 on literature request card, page 48-B.

Swaging Machine

The Fenn Mfg. Co. has announced a heavy duty long-die swaging machine designed for forming heavy



gage, large diameter steel tubing used in steam generator boilers. The machine is equipped with 15 in. dies and hydraulic feeding equipment. Steel tubing will be swaged, reducing its diameter while maintaining a specified wall thickness at the reduced diameter by means of mandrel swaging.

For further information circle No. 334 on literature request card, page 48-B.

Chromium Stripping

Immersion stripping of chromium plated parts with a dry acid replacement salt has been announced by MacDermid, Inc. Chromium plate 0.00002 in. thick can be stripped in 0.5 min. by immersion only. M-629 is used in a solution of 1 lb. to a gal. heated to 180 to 190° F. Rinsed carefully and then replated, the parts showed no whiteness or streaks. Quality of the replate equalled the original plating, and no damage to the nickel plate was reported. M-629 may be used to clean the piping system and nozzles of spray washing machines.

For further information circle No. 335 on literature request card, page 48-B.

Crucible Wash

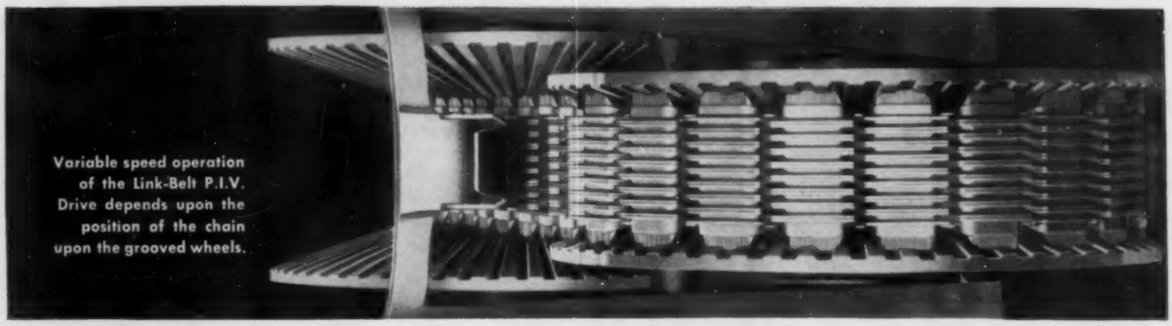
The Beryllium Corp. has announced a new beryllium oxide crucible wash. The product is used to coat the graphite crucibles utilized in melting uranium-base alloys for nuclear ap-

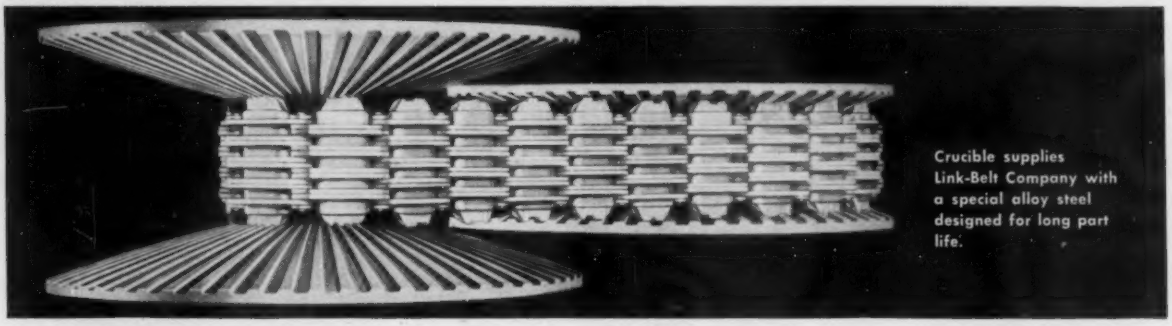
plications. Uncoated graphite crucibles cannot be used because of carbon contamination in the melt. In uncoated crucibles, the carbon pickup may be as much as 1%, whereas the carbon content can be held to approximately 100 p.p.m. using the beryllium oxide coated crucibles.

For further information circle No. 336 on literature request card, page 48-B.

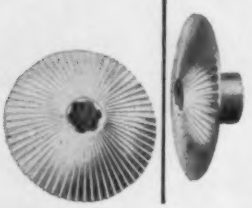
Welding

Air Reduction Sales Co. has announced new welding head manipulator and control console for longitudinal and circumferential welding. The unit was engineered for universal positioning of a welding head and accurate variable speed traverse of the head. Both tungsten inert-gas arc welding and metal inert-gas arc weld-





these
SPECIAL ALLOY STEEL PARTS
keep Link-Belt's P.I.V. Drive on the job



Keeping production operations going at the right speed is the job of this variable speed drive unit produced by Link-Belt Company. Its operation is based on an exclusive drive chain with self-forming metal teeth, which engage with radial grooves in two pairs of cone-shaped wheels.

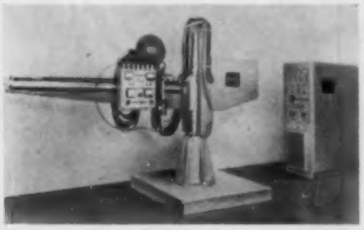
To make these precision wheels requires a steel that can be readily machined, will not distort, and which has high-strength. That's why Crucible furnishes Link-Belt with a special Nitriding BM alloy steel *designed* for this application. After machining the wheels are Nitrided to obtain a minimum surface hardness of 1000 Vickers Diamond Brinnel — about the hardest surface that can be obtained commercially.

When your application requires a tough, machinable, nondeforming alloy steel — call Crucible. One of our many special alloy grades may be the right one for you — or we can develop one to meet your most exacting demands. *Crucible Steel Company of America, The Oliver Building, Mellon Square, Pittsburgh 22, Pa.*

CRUCIBLE first name in special purpose steels

Crucible Steel Company of America

ing automatic heads may be mounted on the manipulator. The electrical console provides all the necessary controls for programming of the welding operation. Electronic timers are pro-



vided for sequence control. Console includes welding power source with current slope control, accessories for control of shielding and back-up gases, and a self-contained water circulating unit.

For further information circle No. 337 on literature request card, page 48-B.

Gold Plating

The development of a doped gold process for use in germanium and silicon semiconductor applications has been announced by the Precious Metals Div., Sel-Rex Corp. Doped with antimony or other elements, depending on the desired physical properties, the new process operates at room temperatures, and produces bright, uniformly distributed gold deposits in required thicknesses, directly from the bath.

For further information circle No. 338 on literature request card, page 48-B.

Gas Generator

Connecticut Gas Atmospheres has announced a new production model of an endothermic gas generator of 1000 c.f.h. capacity. This generator is equipped with a reversing valve which allows changes in the direc-

tion of the gas flow. The reversal of the gas flow eliminates sooting and pressure build-up, it prevents deterioration of the catalyst, and it keeps the furnace flow-meters clear.

For further information circle No. 339 on literature request card, page 48-B.

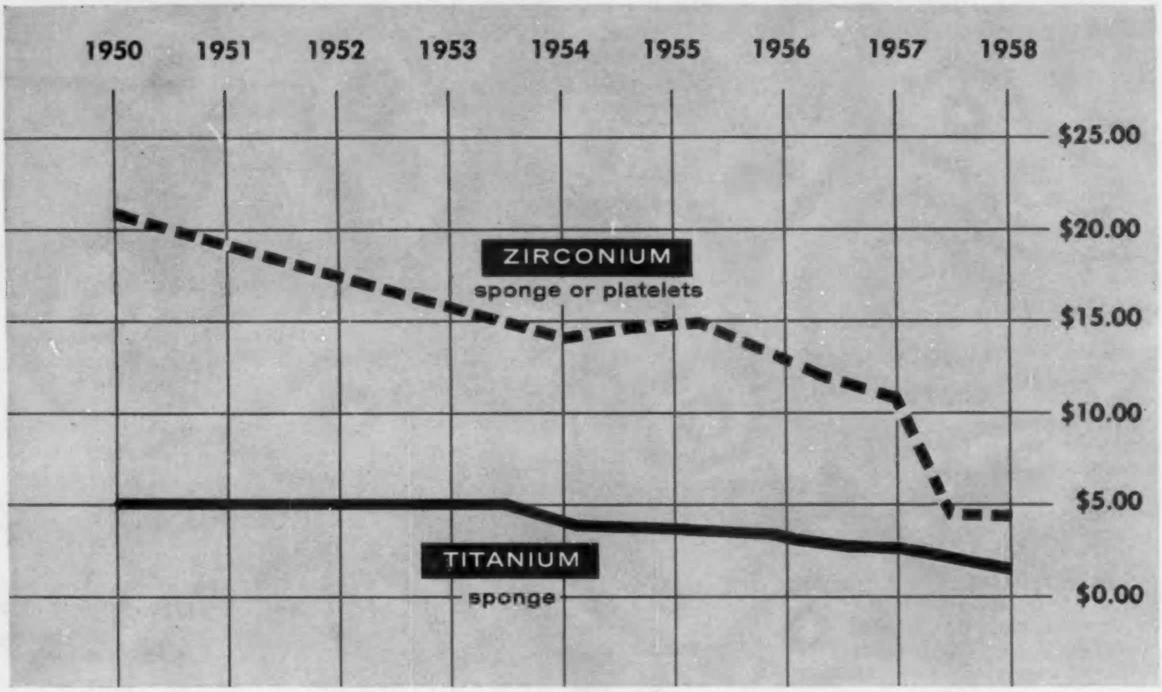
Burnishing Compound

Oakite Products, Inc., has announced a new compound for use with all types of barrel finishing media or with self-tumbling work. It may be used on aluminum, copper, brass, nickel-silver, gold, and mild and hardened steel. It has a pH of 8.5 to 8.6 and contains no ingredients which would encourage the growth of bacteria or cause dermatitis. Solution concentrations are 1 to 2 oz. per gal. of water.

For further information circle No. 340 on literature request card, page 48-B.

Heat Exchanger

A newly designed heat exchanger has been announced by the Niagara Blower Co. for installations requiring the cooling of fluids or condensing vapors. The unit consists of an arrangement of heavily finned tubes in a casing through which air is drawn by two propeller-type fans. Heat



Available soon at lower prices

ZIRCONIUM AND TITANIUM FOR INDUSTRIAL USE

Now is the time to do some new thinking about titanium and zirconium. These metals with their many advantages will soon be *much more plentiful* at *much lower cost.* Reason: U.S.I. will be coming onstream shortly with a 10-million pound per year titanium plant AND a zirconium plant which will supply one million pounds of that metal to industry.

Zirconium from the new plant will sell for considerably less than current prices. Here's why: U.S.I. will use the most economical production technique ever developed for reducing metallic chlorides – a semi-continuous sodium reduction process. This process has possibilities of reducing titanium prices in the future as well.

So think again about zirconium and titanium for industrial equipment. Remember that they are lighter than other metals – a pound goes farther. Remember that they are more durable than other metals–a fabricated product lasts longer.

Write to Bill Greenleaf, U.S.I. Manager of Metals Department, for more information on these new metals from U.S.I.

WHAT CAN YOU DO WITH TITANIUM AND ZIRCONIUM AT LOWER PRICES?

In the future titanium sponge prices are expected to drop to about $2.00 a pound, with a corresponding drop in the prices of mill products. At these prices the exceptional strength-to-weight ratio and corrosion resistance of titanium can be put to work in the aircraft, marine, automotive, chemical and allied fields.

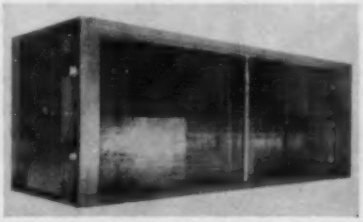
Or consider the eventual price of U.S.I. commercial grade zirconium: an estimated $3.00 a pound for platelets and 2 or 2½ times this price for the average mill product. This price will make zirconium practical for chemical equipment, marine equipment, food equipment and surgical metals among other uses. Zirconium has light weight, high structural strength, excellent corrosion and heat resistance; and reactor-grade zirconium has outstanding nuclear properties.

U.S.I. INDUSTRIAL CHEMICALS CO.

Division of National Distillers and Chemical Corporation
99 Park Avenue, New York 16, N. Y.


Bar Casting
Machine

transfer is from the fluid through the tube walls and extended surfaces to air that is exhausted into the atmos-



phere. Units come in four sizes to 63 in. high and 126 in. long.

For further information circle No. 341 on literature request card, page 48-B.

Thermal Conductivity Testing

Parameters, Inc., has announced an automatic thermal conductivity test console. Employing the guarded hot plate principle, this unit conforms to the requirements of ASTM Specification C177-45. Hot surface tempera-

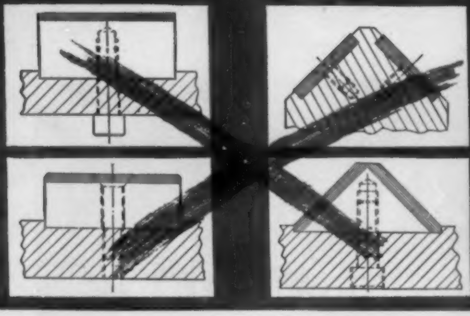
tures are automatically maintained in the range of 100 to 1400° F. with cold surfaces controlled between 60 and 600° F. Coefficients of thermal conductivity up to 5.0 Btu./sq. ft. hr. deg. Fahr./in. can be determined.

For further information circle No. 342 on literature request card, page 48-B.

Plating Bath Additive

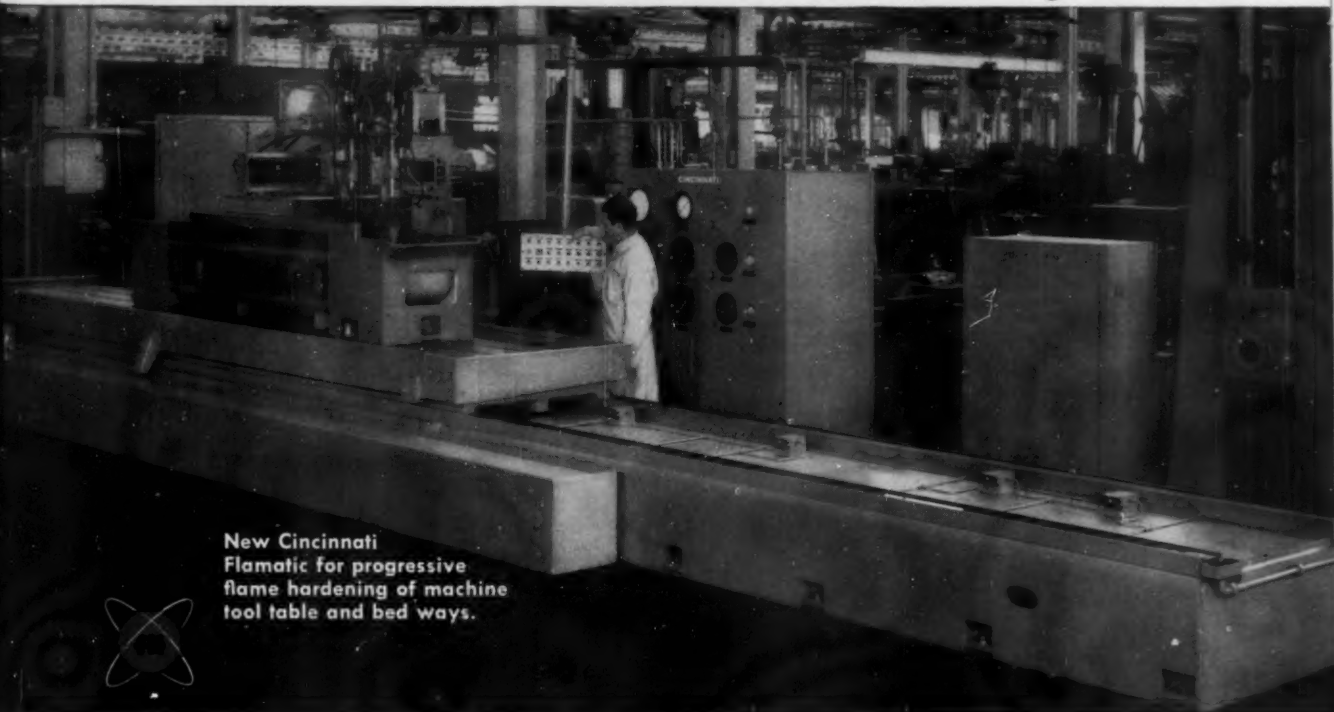
A new zinc additive for plating operations has been announced by Wagner Bros. It is produced as a light tan powder, but is dissolved in water prior to use in barrel and rack plating operations. An original charge of 1 lb. of the new zinc is added to 100 gal. of purified zinc solution, and adding 2 to 4 oz. of the agent per 100 gal. per day will maintain the brightness.

For further information circle No. 343 on literature request card, page 48-B.



eliminate costly ways to get hardened ways...

use the flamatic way!



New Cincinnati Flamatic for progressive flame hardening of machine tool table and bed ways.

Cast iron machine tool table and bed ways are now being surface hardened on this new Cincinnati Flamatic®. Uniform hardness of Shore 75-80 is achieved. This Flamatic method results in substantial cost savings over methods currently employed of fastening hardened steel wear strips or sheets to cast or welded components in sliding contact.

The reciprocating work table of the Flamatic can accommodate castings up to 20 feet long x 44 inches wide x 40 inches high, on which integrally cast ways are to be hardened. Table feed is infinitely variable between 3" and 15" per min., and rapid traverse is at 25 ft. per min. Flame heads are mounted on a rail, powered for rapid positioning of the flame heads to the ways to be hardened. The flame head assembly includes water spray quench and a tracer mechanism, which at all times maintains the prescribed gap distance of the flame from the way . . . compensating for any distortion of the casting.

Oxy-acetelyne fuel gas is used; however, the unit will operate on propane or natural gas. Complete operating controls are located on a pendant station. Flame hardening of work such as columns, rolls, long bars and shafts, which can be held between centers on the table, is also accomplished.

Check into Flamatic surface hardening for savings in your production processes. Call in a Process Machinery Division field engineer.

CINCINNATI

flamatic and inductron

hardening machines

PROCESS MACHINERY DIVISION
THE CINCINNATI MILLING MACHINE CO.
CINCINNATI 9, OHIO, U. S. A.

APPLICATION and EQUIPMENT new literature

344. Heat Resistant Castings

Up-to-date property information on heat-resistant casting alloys has been compiled to add to the data on corrosion-resistant alloys which were assembled in 1954. Mechanical properties at room and elevated tempera-

tures, compositions, physical properties, heat treatment, design and fabricating considerations, corrosion resistance and applications are given for 14 different heat-resistant casting alloys. The 14 corrosion resistant casting alloys are described in much the same way and are included in the data folder. *Alloy Casting Institute*

345. Abrasive Cleaning
Catalog 57-WX on brush types, sizes, speeds, filaments. Aids to power brush selection. *Pittsburgh Plate Glass, Brush Div.*

346. Abrasives
New catalog on various types of shot and grit abrasives. SAE specifications and types of cleaning and peening methods. *Cleveland Metal Abrasive.*

347. Air Washers
Bulletin No. 256 on acid-proof air washers for ventilation systems. Construction and accessories. *Automotive Rubber Co.*

348. Alloy Steel
Data book on the selection of the proper alloy steel grades for each manufacturer's needs. *Wheelock, Lovejoy*

349. Alloy Steel
16-page book on type 9115 low-alloy high-strength steel. Properties, fabrication, welding. *Great Lakes Steel*

350. Alloy Steel Castings
Specifications for T-loy 34 and T-loy 42. Heat treatment and characteristics. *Unitcast Corp.*

351. Alloy Tools
44-page book on cast Stellite tools for metal cutting. *Haynes Stellite*

352. Aluminum Die Castings
Bulletin on design and manufacture of aluminum die castings. *Hoover Co.*

353. Aluminum Alloy
4-page brochure on alloy 417. Composition, properties, government specifications and applications. *Apex Smelting Co.*

354. Aluminum Extrusions
Folder lists alloys used, finishes, trade phraseology. *General Extrusions, Inc.*

355. Ammonia
8-page booklet on uses of dissociated ammonia in industry. Dissociation process and applications in bright annealing, furnace brazing, powder metallurgy, bright hardening. *Armour Ammonia Div.*

356. Ammonia Atmospheres
12-page bulletin B-52 on dissociated ammonia furnace atmospheres. *Drever*

357. Annealing
Bulletin SC-146 on cycle annealing in atmosphere and direct-fired furnaces. Steels annealed and hardnesses obtained. *Surface Combustion*

358. Atmosphere Furnace
4-page description of furnace which heat treats, quenches and cools under controlled atmosphere. Furnace for solution heat treating of aluminum and oven for tempering springs. *W. S. Rockwell Co.*

359. Atmosphere Furnace
4-page bulletin on automatic continuous heat treating furnace. Operational advantages, principle of operation, capacity, construction. *American Gas Furnace Co.*

360. Atmosphere Furnaces
4-page bulletin on furnaces for hardening high carbon and high speed tool steels. Diagrams, specifications and performance data. *Lindberg Engineering Co.*

361. Atmospheres
12-page bulletin on use of protective atmospheres to prevent deterioration of metals during various heat treating processes. *General Electric*

362. Austempering
12-page bulletin 206 describes isothermal heat treating and equipment. Properties obtained by different quenching procedures for several steels. *A. F. Holden*

363. Bimetal Applications
44-page booklet, "Successful Applications of Thermostatic Bimetal", contains uses, formulas, calculations. *W. M. Chace*

364. Blast Cleaning
12-page manual on blast cleaning abrasives. Characteristics of various kinds. SAE shot and grit sizes. *Pangborn Corp.*

365. Blast Cleaning
Bulletin 332B on new alloy for wear plates in Rotoblast wheel housings, drum heads and other parts subject to abrasion. *Pangborn Corp.*

366. Boron Stainless
8-page booklet on composition, structure, corrosion resistance, welding and mechanical properties of 1% boron stainless steel. *Superior Steel Corp.*

367. Brazing
52-page publication GEA-3193C on how and where to use electric furnace brazing. Limiting creep of brazing metal, selecting the brazing metal, strength of furnace-brazed parts, how to braze cast iron, causes of distortion and other topics considered. *General Electric Co.*

368. Brazing
8-page reprint on dip brazing of aluminum assemblies. Design of parts, equipment used, maintenance, tooling. *Ajax Electric*

369. Buffing Compounds
Bulletin B-7 lists various compounds and gives applications. *Apothecaries Hall*

370. Burners
New Buzzer catalog on industrial gas burners and gas furnaces for heat treating carbon and alloy steels. Pot furnaces and melting furnaces. *Charles A. Hones*

371. Burners
Bulletin 58 on gas burners shows design and installation arrangements. Table of capacities. *North American Mfg.*

372. Calibration
12-page brochure on proving rings in weighing and force measuring systems. Their uses, construction and operation. *Morehouse Machine*

373. Carbon Refractories
Catalog section on carbon products for cupola furnaces gives physical properties of carbon refractories and describes applications. *National Carbon*

374. Carbonitriding
Bulletin 241 on gas-fired radiant-tube furnace for carbonitriding and other heat treating. *Lindberg Engineering*

375. Carburizing
Data folder on Aerocarb E and W water-soluble compounds for liquid carburizing. Case depth vs time curves. Per cent carbon and nitrogen penetration curves. *American Cyanamid*

376. Carburizer
Data sheet on Perliton 400, water-soluble carburizer. Operation of bath. Case depths. *E. F. Houghton & Co.*

377. Case Hardening
Handbook on Nitrocycle case hardening and how it reduces finishing costs. *Oil Well Supply Div., U.S. Steel*

378. Castings
Bulletin 3150-G on castings for heat, corrosion, abrasion resistance. *Duraloy*

379. Castings
8-page Bulletin 13 on chromium-molybdenum gray iron. Applications, engineering and design data. *Advance Foundry*

380. Centrifugal Castings
Folder on which centrifugal castings are available. Compositions, properties, standard designations. *Sandusky Foundry and Machine Co.*

381. Ceramics
4-page bulletin D2-56 on physical properties of 10 industrial ceramics. Fabrication methods and important service features. *McDanel Refractory Porcelain Co.*

382. Chromium
Mining of chromium ore in Rhodesia described in Vancoram Review, Fall & Winter 1956. *Vanadium Corp.*

383. Chromium Plating
Bulletin CFC-1 on advantages of crack-free chromium plating process. *United Chromium Div., Metal & Thermit Corp.*

384. Chromium Treatment
4-page bulletin on atom exchange process for creating a chromium-rich surface on ferrous metals. *Alloy Surfaces Co.*

385. Cleaning
5-page Bulletin 86 on improving properties of brass and copper surfaces with ammonia persulfate. *Becco Chemical Div.*

386. Cleaning
Folder on di-phase cleaning gives equipment, construction features, spray and blow-off features, heating systems. *Solventol*

387. Coated Metals
New bulletin on roll coating shows how it is done and includes samples. *Roll Coater, Inc.*

388. Coating
12-page bulletin on plastic coating materials. Methods of application, uses, variety in color and properties. *Chemical Products Corp.*

389. Cold Finished Steel
16-page booklet on 10 grades of cold finished steels. Analysis, machinability, heat treatment, wear resistance. *Jones & Laughlin*

390. Cold Rolled Steels
32-page booklet on stainless, alloy and carbon spring steels, and other specialties. Melting, temper, finishes. *Crucible Steel*

391. Continuous Casting
24-page book, "Better by the Mile", describes how the Rossi continuous casting machine works. History of continuous casting. *Scovill Mfg.*

392. Controllers
12-page booklet on temperature controls and special purpose controllers. Operation, design, installation. *Assembly Products, Inc.*

393. Conveyors
Bulletin MF-200 on conveyor standardization describes prefabricated sections for making customized conveyors. *May-Fran Engineering*

394. Copper Alloys
60-page catalog on phosphor bronzes, nickel silvers, beryllium copper, cupronickel. Chemical and physical data. Engineering tables. *Riverside-Alloy Metal*

395. Copper Alloys
New 28-page specification index compares trade names and specifications of various agencies. Compositions of Anaconda alloys. *American Brass Co.*

396. Corrosion
16-page bulletin on how corrosion occurs in stainless steel food processing and dairy equipment and how it can be prevented. *Diversey Corp.*

397. Corrosion Inhibitor
Folder on corrosion inhibitor for aluminum and steel. Applications. *Virginia-Carolina Chemical Corp.*

398. Corrosion Protection
New 16-page bulletin on corrosion proof construction materials includes sections on corrosion proof cements, tank linings, protective coatings and others. *Atlas Mineral Products*

399. Corrosion Resistance
20-page bulletin on copper alloys for corrosion resistance. Table gives applicability in 150 media. *Ampco*

400. Degreasers
Folder on vapor and solvent degreasers describes equipment and advantages. *Randall Mfg.*

401. Degreasing
34-page booklet on vapor degreasing. Design, installation, operation and maintenance of equipment. *Circo Equipment*

402. Descaling
24-page book "Handling Metallic Sodium" with special reference to sodium hydride descaling. *U.S. Ind. Chem.*

403. Descaling
Bulletin 1184 on descaling salt for desanding and cleaning castings. *Hooker Electrochemical*

404. Descaling
Bulletin on system of descaling stainless, alloy steels and titanium after heat treating. *Kolene Corp.*

405. Dryers
New 52-page Bulletin D-100 on dryers for air, gas and liquids for low dew points. *C. M. Kemp Mfg. Co.*

406. Ductile Iron
2-page Bulletin 14 describes characteristics, production, effect of heat treatment, types. *Advance Foundry Co.*

407. Electric Furnace
Bulletin 5610 on rocking electric furnace with motor-driven electrodes. Ratings, special features and characteristics. *Detroit Electric Furnace Co.*

408. Electric Furnaces
Folder on electric furnaces with zone control, temperature indication, automatic control. *L & L Mfg. Co.*

409. Electric Furnaces
12-page bulletin on furnaces for hardening high-speed steel. Diamond block method of atmospheric control. *Sentry*

410. Electric Furnaces
8-page Bulletin 570 on heat treating, melting, metallurgical tube, research and sintering furnaces. Custom designs for special requirements. *Pereny*

411. Electric Furnaces
Data sheet describes and gives specifications of standard non-metallic resistor furnaces. *Harrop Electric Furnace Div.*

412. Electrodes
20-page bulletin on Croloy welding electrodes. Specifications, coatings, applications, properties. *Champion Rivet Co.*

413. Electrocoated Wire
8-page bulletin on new wire materials —Nickelply and Brassply, electrocoated steel wire. How it may be formed, bent and twisted without breaking the coating. *National Standard*

414. Electrolizing
24-page booklet on process for depositing hard, dense, non-magnetic alloy on metal surface. Surface characteristics, test results. *Electrolizing Corp.*

415. Electrolytic Etching
12-page article in Metal Digest, V. 1, No. 2, covers the theory and practice of electrolytic etching of metallographic specimens. *Buehler, Ltd.*

416. Electron Microscope
12-page bulletin gives construction and

PUT your products in the barrel
TAKE your profits out

A great way to save money is to barrel finish metal parts by the hundred instead of manually finishing one part at a time.

Next time a job of grinding, deburring or buffing proves too costly on a wheel, try it in a barrel. The results are often so surprising that barrel finishing becomes an exciting and profitable game.

One Oakite customer changed to barrel methods to deburr curved stainless steel strips that are 14 inches long. The cost for deburring 20,000 strips was reduced from $3,000 to $125.

FREE For a copy of *"Precision Barrel Finishing"* write to Oakite Products, Inc., 26H Rector St., New York 6, N. Y.

SPECIALIZED INDUSTRIAL CLEANING
OAKITE
MATERIALS · METHODS · SERVICE
SCIENCE

Technical Service Representatives in Principal Cities of U.S. and Canada
Export Division Cable Address: Oakite

operation. Electron optical system, accessories. *Philips Electronics*

417. Electroplating
12-page booklet on 9 ways to cut electroplating costs. Surface preparation, how to select the proper compound, determining solution life, rinsing, racking. *Diversey Corp.*

418. Environmental Cabinets
Folder on mechanically operated cabinets for temperatures from −225 to +350° F. *Webber Corp.*

419. Fatigue of Magnesium
18-page paper, "Plastic Flow and Work Hardening Phenomena in Magnesium Alloys During Fixed-Deflection Fatigue Tests". *Dow Chemical*

420. Finishes
Pocket-sized booklet covers blackening compounds, alkaline cleaners, strippers, lacquers, enamels, rust removers. *Enthone*

421. Flaw Location
4-page folder on dye penetrant method of flaw location. Pre-cleaning, applying penetrant, removing excess penetrant, applying developer and interpreting results are discussed. *Turco*

422. Flow Meters
Bulletin 203 on flow meter for gas used in heat treating. *Waukee Eng'g*

423. Finishing
New 52-page barrel finishing handbook. Modern processes described. *Almco Div.*

424. Finishing
16-page Bulletin 51 on metal finishing systems considers automatic, semi-automatic and batch-type systems. Various installations shown. *Despatch Oven*

425. Fluoroscopy
New 6-page reprint on modern techniques for using electronic fluoroscopy in examination of metals. Mechanism of image intensification, effect of target size on X-ray image, penetration effectiveness of various methods. *Philips Electronics*

426. Forgings
Bulletin on forge steelmaking, open die forging, machining, heat treating and finishing. *National Forge*

427. Formed Shapes
26-page catalog No. 1555 contains drawings and dimensions of more than 100 shapes. *Roll Formed Products Co.*

428. Forging
Cost study compares seamless long welding necks and built-up necks. *Lenape Hydraulic Pressing & Forging Co.*

429. Forgings
20-page bulletin on drop forgings describes equipment, metals and metallurgy, heat treating, cleaning and finishing. *J. H. Williams & Co.*

430. Furnace
New bulletin on basic principles of electric furnace design. Cutaway models of 8 furnaces. Cost factors. *Holcroft & Co.*

431. Furnace Belts
44-page catalog describes metal belts for quenching, tempering, carburizing and other applications. *Ashworth Bros.*

432. Furnace Fixtures
16-page catalog on baskets, trays, fixtures and carburizing boxes for heat treating. 66 designs. *Stanwood*

433. Furnace Fixtures
Bulletin 111 on cast Ni-Cr fixtures for gas carburizing. *Fahralloy*

434. Furnace Loader
Bulletin on loader for heat treat furnaces. *Michigan Crane & Conveyor*

435. Furnaces
4-page reprint on high thermal head furnaces for continuous slab heating installation at Atlas Steels, Inc. Cross section view of radiamatic unit. *R-S Furnace Co.*

436. Furnaces
Bulletin on electric heat treating furnaces describes five series and accessories. *Lucifer Furnaces*

437. Furnaces
Folder on recirculating furnaces illustrates and describes 9 models and endothermic gas generator. *Standard Fuel Engineering Co.*

438. Furnaces
Bulletin No. 461 on gas, oil and electric furnaces. 17 different installations described. *Electric Furnace Co.*

439. Furnaces
Bulletin on graphite tube furnaces for temperatures to 5000° F. Operating limitations, auxiliary and control equipment. *Harper Electric*

440. Furnaces
Data on line of melting, heating and heat treating furnaces for ferrous and nonferrous metals. *Loftus Engineering*

441. Fused Silica
Folder on fused silica which is resistant to high temperatures, thermal shock, acids and has high electrical insulating value. *Amersil*

442. Galvanometers
12-page bulletin No. 320 on three different types of galvanometer. Factors affecting selection. *Rubicon*

443. Gas Analyzer
Bulletin 175 on sonic analyzer gives principle of operation, method of measurement, sensitivity. *National Instrument Laboratories, Inc.*

444. Gas Unit
Bulletin HD-257 on gas preparation unit gives composition and chemical reactions, advantages. *Hevi Duty Electric*

445. Globar Furnaces
Bulletin 153 describes nine types of furnace using silicon carbide heating elements for temperatures to 2600° F. *Hevi Duty*

446. Gold Plating
Physical, thermal, chemical, electrical, diffusion and optical properties of electroplated gold. Uses. *Technic, Inc.*

447. Graphite
20-page brochure on significance of graphite as electrodes, anodes, molds, and specialties in electrometallurgy and electrochemistry. *Great Lakes Carbon*

448. Graphite
4-page catalog section S-5050 on impervious graphite and resin-base cements for corrosive service. 2-page table gives recommendations for commercial applications. *National Carbon*

449. Grinding and Polishing
New accessory list for abrasive belt unit. Specifications and operation of continuous abrasive belt machine. *Grinding & Polishing Machinery Corp.*

450. Hardness Conversion Tables
Celluloid card, 2¾ x 4¾ in., gives approximate relationship between Brinell, DPH (Vickers), Rockwell and Shore Scleroscope hardness values and corresponding tensile strength of steels. *International Nickel*

451. Hardness Numbers
Pocket-size table of Brinell hardness numbers incorporating other tabular information. *Steel City Testing*

452. Hardness Tester
20-page book on hardness testing by Rockwell method. *Clark Instrument*

453. Hardness Tester
Data on hardness testing scleroscope with equivalent Brinell and Rockwell C numbers. *Shore Instrument*

454. Hardness Testers
20-page bulletin on models, applications and how to use superficial hardness testers. *Wilson Mechanical Instrument*

455. Hardness Testing
Bulletins on Wolpert-Gries machines for standard Rockwell tests. Motorized reflex type for Brinell tests. *Gries Industries*

456. Heat-Resistant Castings
16-page bulletin on design, foundry practice and applications. *Electro-Alloys*

457. Heat Treating
Article on heat treating of gears and parts at New Process Gear Corp. in Heat Treat Review, Vol. 8, No. 1. *Surface Combustion*

458. Heat Treating
16-page book on heat treating and pickling of stainless steels. Annealing, hardening and tempering temperatures and resulting properties. *Crucible Steel*

459. Heat Treating
Reference sheet gives procedures for preparing parts for heat treating. *Metal Treating Institute*

460. Heat Treating
New 2-page bulletin on controlled atmosphere, multi-zone pusher furnaces. Forced convection heating explained. *Ipsen Industries*

461. Heat Treating
Monthly bulletin on used heat treating and plating equipment, available for immediate delivery. *Metal Treating Equipment Exchange*

462. Heat Treating Ammonia
24-page "Guide for Use of Anhydrous Ammonia" describes heat treating and other metallurgical uses. *Nitrogen Div.*

463. Heat Treating Fixtures
4-page folder on retorts, baskets, trays, carburizing boxes, fans for heat treating. *Aluminum & Architectural Metals Co.*

464. Heat Treating Fixtures
32-page Catalog G-10 covers heat and corrosion resistant fabricated alloy products. Includes furnace muffles, trays, fixtures, retorts, pit-type furnace equipment, salt bath equipment, pickling and plating equipment. *Rolock, Inc.*

465. Heat Treating Fixtures
24-page catalog on heat and corrosion-resistant equipment for heat treating and chemical processing. 30 classifications of equipment. *Pressed Steel*

466. Heat Treating Fixtures
12-page bulletin on wire mesh baskets for heat treating and plating. *Wiretex*

467. Heaters
Bulletin on immersion heaters for electroplating solutions. *Glo-Quartz*

468. Heating Element
New 12-page catalog on 35-20 nickel-chromium-iron heating element. Temperature-resistance curve, physical property tables and factors to consider in designing furnace elements. *Hoskins Mfg. Co.*

469. High-Strength Steel
48-page book on T-1 steel, its properties and applications. *U.S. Steel*

470. High-Strength Steel
48-page booklet on applications of seven nickel-copper high-strength low-alloy steels. *International Nickel Co.*

471. High-Strength Steel
Data sheet and 16-page folder on Vasco-Jet 1000, 5% chromium air hardening steel. Mechanical properties, fatigue strength, heat treatment and surface properties. *Vanadium-Alloys Steel Co.*

472. High-Temperature Alloys
Data on wrought high-temperature Discaloy, K42B, and Refractaloy. Applications, advantages, low-temperature applications, processing and properties. *Westinghouse Electric Co.*

473. Identifying Stainless
Cardboard chart outlining systematic method for rapid identification of unknown or mixed stocks of stainless steels. *Carpenter Steel*

474. Induction Heaters
8-page bulletin on new electronic induction heaters. Specifications for four models. Special features. *General Electric*

475. Induction Heating
12-page booklet B-6519 on equipment for induction heating for forging, hardening, annealing and metal joining. *Westinghouse Electric*

476. Induction Heating
60-page catalog tells of reduced costs and increased speed of production on hardening, brazing, annealing, forging or melting jobs. *Ohio Crankshaft*

477. Induction Heating
36-page bulletin on high-frequency induction heating unit for brazing, hardening, soldering, annealing, melting and bombarding. *Lepel*

478. Induction Heating
Folder on high-frequency induction heating includes diagram of water-cooled, air-cooled and variable output work unit. *Cincinnati Milling Machine Co.*

479. Induction Heating
Folder 15C8053C gives advantages of induction heating and specifications and dimensions of induction heater. *Allis-Chalmers*

480. Induction Melting
Bulletin 70 on furnaces. Controls, designs. *Inductotherm Corp.*

481. Industrial Equipment
12-page catalog on finishing systems, cleaning, pickling, rustproofing equipment, ovens, conveying equipment. *R. C. Mahon Co.*

482. Inoculant
New 96-page booklet on SMZ alloy, an inoculant for cast iron. Metallurgical aspects of inoculation. How to inoculate irons. *Electro Metallurgical Co.*

483. Impact Testing
Bulletin on machine for Izod, Charpy and tension testing. *Riehle*

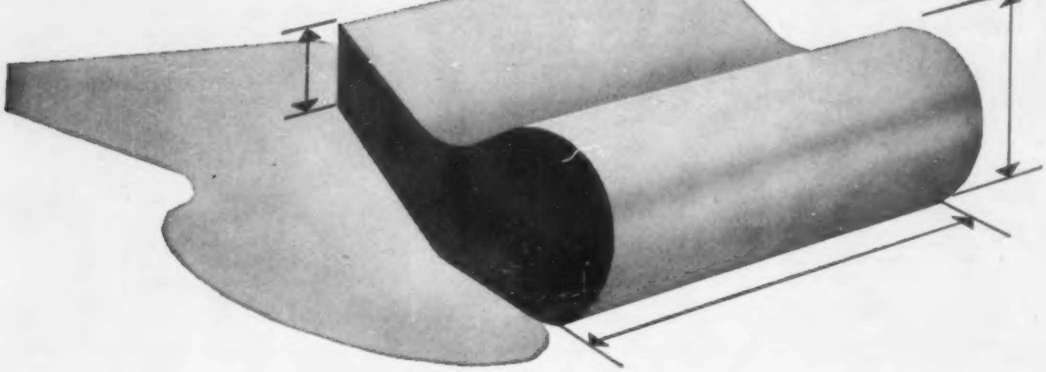
484. Instruments
12-page condensed catalog of instruments and controls for pressure, flow, temperature, gas analysis. *Hays Corp.*

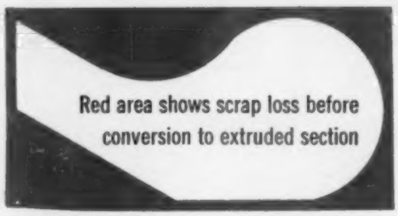
485. Instruments
32-page bulletin 427-1 on electronic indicators, recorders and controllers, of the electrical bridge, self-balancing type. *Foxboro*

486. Investment Castings
4-page folder on frozen-mercury and lost-wax processes for ferrous and nonferrous metals. *Alloy Precision Castings*

52% saving

reported with J&L hot extruded cold drawn pawl section





This pawl was previously milled from a ¾" x 1½" hot rolled oil hardening tool steel. Conversion to a cold drawn extruded section cut cost from 45¢ to 22¢ per part.

Here's how extruded sections can cut your cost:

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2. Reduce scrap losses almost to zero.
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4. Reduce inventories because extrusions are quickly available.

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487. Lab Test Dies
Complete information on multi-motion laboratory test specimen dies. *Haller, Inc.*

488. Laboratory Equipment
32-page bulletin on scientific apparatus and methods includes a 16-page discussion of the recorder. Catalog of other apparatus including combustion furnace, carbon analyzers. *E. H. Sargent & Co.*

489. Laboratory Equipment
New bulletin on cutting test specimens describes methods for different types of metals. Price list. *Sieburg Industries*

490. Laboratory Equipment
Folder on 5 types of laboratory mixers. Specifications for each type. *Mixing Equipment Co.*

491. Leaded Steel
4-page bulletin on leaded alloy steel gives analysis, properties, advantages, machinability. *Horace T. Potts Co.*

492. Leak Detector
Data sheet on Model 4902 leak detector includes description, operation, accessories. *NRC Equipment Corp.*

493. Lithium
15-page tabbed booklet describes properties, uses, research potentials, availability of lithium, its compounds. *American Lithium Institute, Inc.*

494. Lubricant
8-page folder describes use of molybdenum disulfide lubricant in cold forming, cold heading and other applications. Case histories. *Alpha Molykote Corp.*

495. Lubricants
New edition of 4-page bulletin lists 44 colloidal and semi-colloidal dispersions of graphite, molybdenum disulfide, zinc oxide and others. *Acheson Colloids Co.*

496. Lubricants
16-page brochure on history and development of molybdenum disulfide lubricants. Selection table, uses, bonded solid film lubricating coatings. *Alpha Molykote Corp.*

497. Magnesium
4-page reprint on making the earth satellite. *Brooks & Perkins*

498. Magnesium Extrusions
36-page bulletin gives values of moment of inertia, section modulus and radius of gyration of bars, tubing, angles, channels, tees, zees and other sections. *Dow Chemical*

499. Magnesium-Thorium Alloys
11-page article in Magazine of Magnesium on properties and characteristics of magnesium-thorium alloys. *Brooks & Perkins*

500. Malleable Castings
Continuing series of information bulletins covering latest techniques and practices in modern malleable casting. *Malleable Founders' Society*

501. Malleable Iron
8-page bulletin on making ferritic and pearlitic malleable castings. *Wagner Malleable Iron Co.*

502. Metal Cutting
8-page Bulletin 5705 on airbrasive cutting of hard, brittle materials. Specifications, how it works, applications. *S. S. White Industrial Div.*

503. Metallograph
8-page catalog E-240 on research metallographic equipment discusses microscope unit, illuminator, optical equipment, camera, focusing arrangements. *Bausch & Lomb*

504. Melting Furnace
New folder on the new Heroult furnace. Cutaway shows design highlights. *American Bridge Div.*

505. Microhardness Tester
Bulletin describes the Kentron microhardness tester. *Torsion Balance Co.*

506. Microscopes
40-page catalog on metallographs, metallurgical, toolmakers, stereoscopic, polarizing, phase and other microscopes. *Unitron Instrument Div., United Scientific*

507. Mixers
28-page booklet on four portable propeller-type mixers. Motors, propellers, mixing-heads, applications described. *Mixing Equipment Co.*

508. Moisture Measurement
12-page bulletin on how to measure water vapor in air and other gases. Gravometric, dew point and wet and dry bulb methods, and others. *Pittsburgh Lectrodryer*

509. Molybdenum
72-page book gives data on unalloyed molybdenum and four arc-cast alloys. Several pages of references. *Climax Molybdenum*

510. Molybdenum
24-page booklet gives physical and chemical property data on molybdenum powders, wire, alloys. *Sylvania Electric*

511. Nonferrous Wire
Folder gives wire gage and footage chart and data on beryllium copper, phosphor bronze, nickel, silver, brass and aluminum wire. *Little Falls Alloys*

512. Nondestructive Testing
8-page bulletin on equipment for nondestructive testing of bars, rods, tubing. *Magnetic Analysis*

513. Nickel Chromium Steels
8-page bulletin with 28 charts on composition, heat treatment, transformation characteristics and mechanical properties of the standard nickel-chromium steels. *International Nickel*

514. Nitriding
Data on process for nitriding stainless steel. *Standard Steel Treating*

515. Nitrogen Generator
New 6-page bulletin No. I-100 gives flow diagram and explains operation. *C. M. Kemp Mfg. Co.*

516. Oil Quenching
8-page brochure tells in detail how carbon steel often can replace alloy steel when additive is used in the quenching oil. *Aldridge Industrial Oils*

517. Ovens
16-page bulletin No. 53 on various types of core and mold ovens, special ovens and heat treating furnaces. *Carl-Mayer*

518. Photomicrography
Catalog E-210 on sliding base, high or low power photomicrographic equipment. *Bausch & Lomb*

519. Pipe
4-page bulletin on Yoloy continuous weld pipe. Chemistry, properties, corrosion resistance. *Youngstown Sheet & Tube*

520. Pickling Baskets
12-page bulletin on mechanical picklers, crates, baskets, chain and accessories. *Youngstown Welding & Eng'g.*

521. Pickling Baskets
Data on baskets for degreasing, pickling, anodizing and plating. *Jelliff*

522. Plating
New data and specification sheet covering tin plating a wide range of nonferrous thin strip metals. *Somers Brass Co.*

523. Plating
9-page bulletin on copper fluoborate bath for printed circuits. Bath composition, make-up, and control for copper and tin plating. *Baker & Adamson*

524. Plating Solutions
Operating manuals for plating with metal fluoborate solutions. *Baker & Adamson.* See page 191.

525. Potentiometers
Bulletin 270-68 on six-dial thermofree potentiometers. Two models described. *Rubicon Co.*

526. Powdered Metal
Folder on quality control of powdered metal production through use of test-bar service. *Hoeganaes Sponge Iron Corp.*

527. Precious Metals
Data on bright gold, bright silver, rhodium plating and salts. *Sel-Rex*

528. Precision Casting
8-page bulletin on investment castings of various ferrous and nonferrous alloys. *Engineered Precision Casting*

529. Precision Casting
16-page booklet on methods used to produce castings by the "lost wax" method. Compositions of alloys used. *Crucible Steel*

530. Precision Castings
4-page reprint tells how light alloys are cast by the frozen mercury process. Applications, advantages. *Alloy Precision Castings Co.*

531. Precision Castings
Pocket-sized book gives advantages and limitations of lost-wax process. Basic design principles as they apply to investment castings. *Midwest Precision Castings Co.*

532. Product File
30 new products and 500 pieces of literature described in 20-page reprint of items appearing in monthly magazine during second quarter, 1957. *Metal Progress*

533. Protective Coatings
Folder 301 on industrial protective coatings of rubber, neoprene and other materials. *Automotive Rubber Co.*

534. Pyrometer
8-page data sheet 0053 on Land radiation pyrometer. Construction, calibration, uses. *Fielden Instrument Div., Robertshaw-Fulton Controls Co.*

535. Pyrometer Supplies
56-page bulletin P1238 on thermocouples and pyrometer accessories. Engineering data on selection and installation. *Bristol*

536. Quenching
64-page book tells what happens when steel is heated and cooled, describes quenching media, quenching practices, interrupted quenching and cooling methods. *E. F. Houghton*

537. Quenching
Bulletin 120 on use of heat exchangers to provide heat control in quenching bath. *Niagara Blower*

538. Quenching
16-page booklet on modified and full marquenching procedures. Hardness and dimensional control data, cooling curves, case histories. *Sinclair Refining Co.*

539. Quenching Oil
Bulletin 37 on light quenching oil. Effect of agitation on quenching speed. *Sun Oil*

(Continued on page 48-A)

(Continued from page 47)

540. Radiation Equipment
Radiation Digest, March-April 1957, contains cost sheet comparing costs of inspection by electron or gamma-ray irradiation equipment. *General Electric, X-Ray Div.*

541. Rare Earths
12-page handbook on rare earth chemicals, thorium. Applications of rare earths. *Heavy Minerals Co.*

542. Refractories
12-page catalog shows properties of impervious recrystallized alumina and impervious mullite. Shapes into which each is fabricated. *Morganite, Inc.*

543. Refractories
40-page book lists super-refractories for heat treating furnaces and gives data on use in different kinds of furnaces. *Refractories Div., Carborundum*

544. Refractory
Bulletin on castable refractories. How to use them. Properties of four types. *Standard Fuel Engineering*

545. Refractory Cement
Bulletin discusses refractories and heat-resistant concrete. *Lumnite Div.*

546. Refractory Coating
Data on aluminum oxide and silicon carbide coating which may be sprayed on. *Norton Co.*

547. Refractory Metals
8-page bulletin on titanium and zirconium castings and ingots. Corrosion properties given in 3-page table. *Oregon Metallurgical Corp.*

548. Resistance Welding
New 24-page bulletin SP-18 on spot, projection, flash-butt, upset-butt and seam welding. Descriptions of more than 300 mass-produced parts produced by resistance welding. *Taylor-Winfield Corp.*

549. Rolling Mills
Catalog on line of machines for rolling ferrous and nonferrous metals gives descriptions and lubrication and maintenance instructions. *Fenn Mfg. Co.*

550. Rust Preventives
12-page bulletin on water-soluble rust preventive. *Production Specialties*

551. Rust Prevention
Folder on solvent detergent that cleans and protects. For use in spray washing machine. *Oakite Products, Inc.*

552. Rust Prevention
Data sheets describe solvent type and emulsified type rust resisting compounds. *John Swift Chemical*

553. Salt Baths
Reprints 161 and 162 on new advances in hot salt quenching and salt bath quenching of gears. *Ajax Electric*

554. Sand Blasting
4-page bulletin 1256 on sand blasting machines for cleaning, deburring, surface preparation. *Leiman Bros.*

555. Sand Control
32-page book on defects and troubles in foundry and how to remedy them through sand control. *Claud S. Gordon*

556. Saws
Catalog C-55 describes 35 models of metal-cutting saws. *Armstrong-Blum*

557. Shot and Grit
14-page catalog describes cast steel, malleable iron, chilled iron, cut wire and other forms of abrasive and impact cleaning. *Abrasive Shot & Grit Co.*

558. Shotblasting
16-page "Primer on the Use of Shot and Grit". Problems of blast cleaning operations. *Hickman, Williams*

559. Smelting Equipment
48-page booklet 105 on equipment for smelting covers complete furnaces, electrodes and control equipment. *Lectromelt Furnace Div.*

560. Sodium
28-page booklet on using sodium in dispersed form tells how dispersions are prepared and handled, and their advantages. *Ethyl Corp.*

561. Soldering Fluxes
4-page bulletin on line of non-acid, self-cleaning fluxes. How they work. *Lake Chemical Co.*

562. Specimen Mounting
12-page article in Metal Digest, V. 1, No. 1, discusses mounting of metallurgical specimens in plastic. *Buehler, Ltd.*

563. Spinning
32-page booklet shows shapes which may be produced, metals, tolerances, tools used, typical parts. Combinations of spinning and press forming. *Phoenix Products Co.*

564. Stainless
5-page ASL 288 gives high-temperature strength data of 18-8 Ti for long-time service at elevated temperatures. *Babcock & Wilcox*

565. Stainless Castings
28-page booklet of data on stainless castings. Analyses, properties, handling and heat treatment. Typical applications. *Allegheny Ludlum Steel Corp.*

566. Stainless Steel
Booklet on 430 stainless. Properties fabrication. *Sharon Steel*

567. Stainless Steel
12-page bulletin on chromium-manganese austenitic steel. Effect of cold working properties at elevated temperatures, corrosion resistance magnetic permeability. *U. S. Steel Corp.*

568 Stainless Steel
Selector gives machinability, physical and mechanical properties, corrosion resistance of various grades of stainless steel. *Crucible Steel*

569. Steel
Data sheet on high-purity 52100 steel, made by vacuum melting. *Vacuum Metals*

570. Steel
256-page handbook lists sizes, weights, lengths, steels available, shapes. Data on mechanical properties, standard steel compositions, hardness numbers conversions. *Ryerson*

571. Steel Tubing
48-page Handbook F-3 on fabricating and forging steel tubing. Bending, shaping, cutting and joining operations described. *Ohio Seamless Tube*

572. Stress-Strain Recorders
28-page bulletin No. 4215 on 16 standard recorders and 50 models of strain followers, for use on standard testing machines. *Baldwin-Lima-Hamilton*

573. Stripping
3-page usage and instruction sheet on two acid electrolytic stripping compounds. How they are used. *MacDermid, Inc.*

574. Temperature Control
4-page data sheet 660(1) on temperature control equipment for growing germanium and silicon crystals. *Leeds & Northrup*

575. Temperature Conversion
16-page temperature conversion booklet and electromotive force of thermocouple alloys in absolute millivolts. *Wheelco*

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576. Temperature Measurement
New 24-page catalog of heat radiation detectors for continuous temperature measurement to 5000° F. *Leeds & Northrup*

577. Test Bars
18-page bulletin No. 168 on design of test bar patterns, production of test bars, testing procedures. *Federated Metals Div., American Smelting and Refining*

578. Thermocouples
Bulletin on miniature shielded thermocouples. Uses, calibrations, temperature ranges, materials of construction. *Thermo Electric*

579. Thermostats
4-page bulletin on bimetal thermostats. Temperature ranges, ratings, mountings, terminal arrangements. *Stevens Mfg. Co.*

580. Thickness Gage
Folder on pocket-size gage. How to use it. *Ferro Corp.*

581. Thickness Gages
32-page bulletin on beta gage describes sensing, positioning and control units, computing devices. *Tracerlab, Inc.*

582. Thickness Testing
10-page bulletin 2253 on coating thickness gages. Standard and special purpose gages. Data on how to measure nickel coatings on non-magnetic base metals, how to measure nonmagnetic coatings on iron and steel, how to measure nickel coatings on iron and steel. *American Instrument Co.*

583. Titanium Alloy
12-page booklet on C-120AV titanium alloy. Physical properties, elevated-temperature properties, creep, fatigue, welding, machining, heat treatment. *Rem-Cru*

584. Titanium Alloy
Data sheet on MST 6Al-4V high temperature titanium alloy. Creep and fatigue properties. *Mallory-Sharon Titanium Corp.*

585. Tool Steel
44-page stock list is indexed and includes sizes, weights, and analyses. Decimal conversion and hardness conversion tables. *Uddeholm*

586. Tool Steel Failures
124-page book, "Tool Steel Trouble Shooter", analyzes 107 tool failures and assigns causes as among tool design faults, tool steel faults, improper heat treatment, mechanical and operational factors. *Bethlehem Steel*

587. Tool Steel Heat Treat
Bulletin 1147EE on electric furnace for heat treatment of high speed tool steel. *Hevi Duty*

588. Tubing
Chart gives tolerances for seamless and welded mechanical and stainless tubing. *Peter A. Frasse*

589. Tubing
64-page handbook on use of tube mills in manufacture of pipe and tube. Step-by-step description of the electric-weld process. *Yoder Co.*

590. Tubing
28-page catalog on stainless and high alloy pipe and tubing from ⅛ to 40 in. o.d. Describes contour welding of pipe and tubing. *Trent Tube Co.*

591. Tubing
Technical Cards 145-A and 152-A on alloy steel pipe, tubing and welding fixtures. *Babcock & Wilcox*

592. Ultrasonic Cleaning
Folder on Sonogen ultrasonic generator for metal cleaning. *Branson*

593. Ultrasonic Machining
16-page bulletin lists typical machining operations, materials which may be machined ultrasonically, machine features and accessories. *Sheffield Corp.*

594. Ultrasonic Testing
6-page folder on immerscope diagrams instrument and tells how it may be used. *Curtiss-Wright Corp.*

595. Ultrasonics
Data sheets on high-power ultrasonic generators for mass production and ultrasonic scrubber. *Acoustica Associates*

596. Vacuum Furnaces
Articles on commercial vacuum furnaces for metals and alloys and some aspects of vacuum melted metals. *National Research*

597. Vacuum Pumps
Data sheet 4700 on mechanical booster high-vacuum pumps describes their construction, operation and applications. *NRC Equipment Corp.*

598. Vacuum Pumps
28-page catalog No. 752 contains specifications, tables of formulas, constants and conversion factors. Maintenance procedures. *F. J. Stokes*

599. Welded Tubing
12-page booklet on electric-resistance welded steel tubing. Size and gage range charts for square-welded, hot and cold rolled and rectangular-welded, hot and cold rolled tubing. *Revere*

600. Welder
Specifications and construction details for 300, 400 and 500 amp. combination a.c. and d.c. welders. *Lincoln Electric Co.*

601. Welding
Data on welding positioners from 500 to 100,000 lb. capacity. *Harnischfeger*

602. Welding
4-page bulletin on controlled arc power supply. How arc length is controlled, specifications. *Metal & Thermit*

603. Welding
New 12-page bulletin on hydraulic controls for flash-butt welding machines. Manual, semi-automatic and fully automatic operation. *Taylor-Winfield Corp.*

604. Welding Electrodes
4-page folder on physical properties as welded, analysis, tensile strength, elongation, hardness and uses of gas welding rods, bare electrodes, welding wire and metal spray wire. *Page Steel & Wire Div., American Chain & Cable Co.*

605. Welding Equipment
Catalog on Cadweld process and arc-welding accessories. *Erico Products*

606. Wire Cloth
80-page catalog on applications, meshes, baskets, filters. *Cambridge Wire Cloth*

607. X-Ray Unit
Bulletin on portable X-ray unit. Description of unit and accessories. *Balteau Electric Corp.*

608. Zinc
40-page discussion of zinc as a galvanic anode, underground. Theory and practice of zinc anode application to transmission pipe line, gas distribution systems, transmission line towers, ground rods, grounding cells and domestic oil tanks. *American Zinc Institute*

609. Zirconium
7-page bibliography on properties of zirconium and its alloys. *Columbia-National Corp.*

610. Zirconium
New 18-page pocket-sized book on manufacture, properties, metallography, machining, metal powders. Extensive bibliography. *Titanium Alloy Mfg. Div.*

611. Zirconium
12-page booklet on uses, properties and methods of production of zirconium and hafnium. *U.S. Industrial Chemicals Co.*

August, 1957

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347	372	397	422	447	472	497	522	547	572	597	

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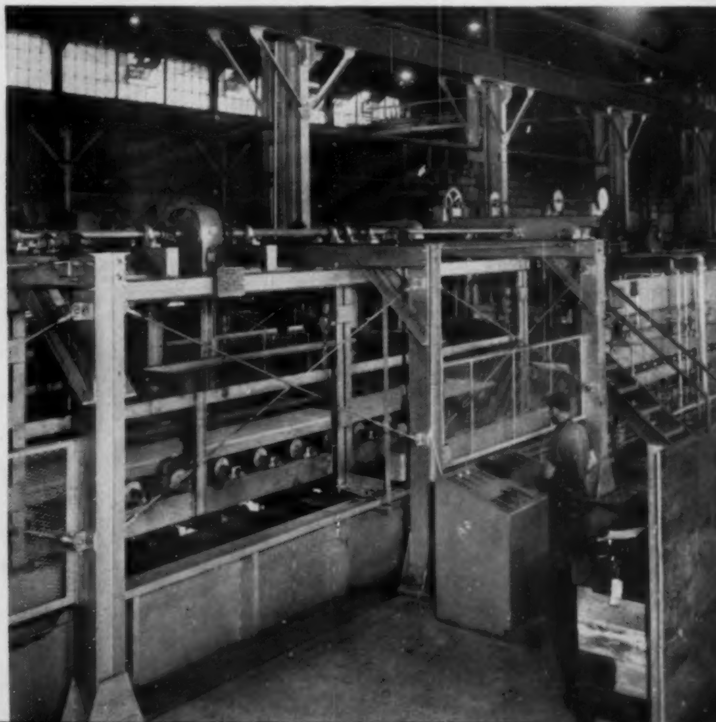
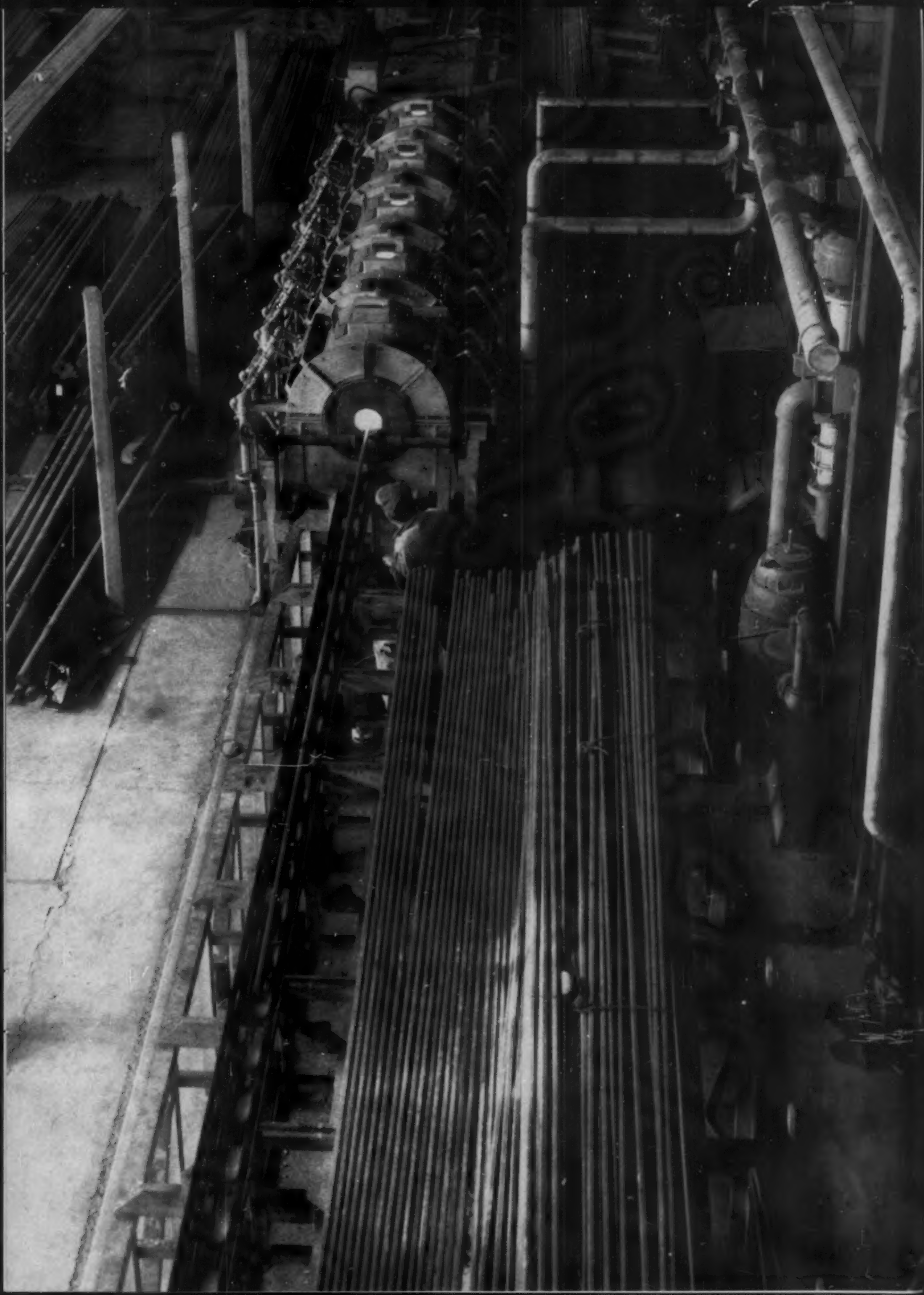
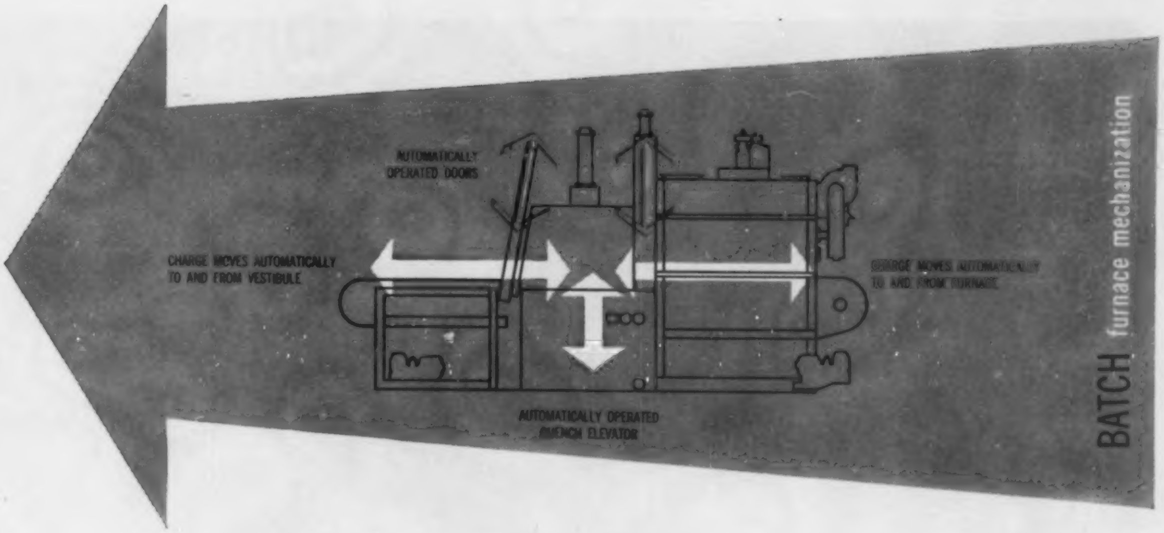
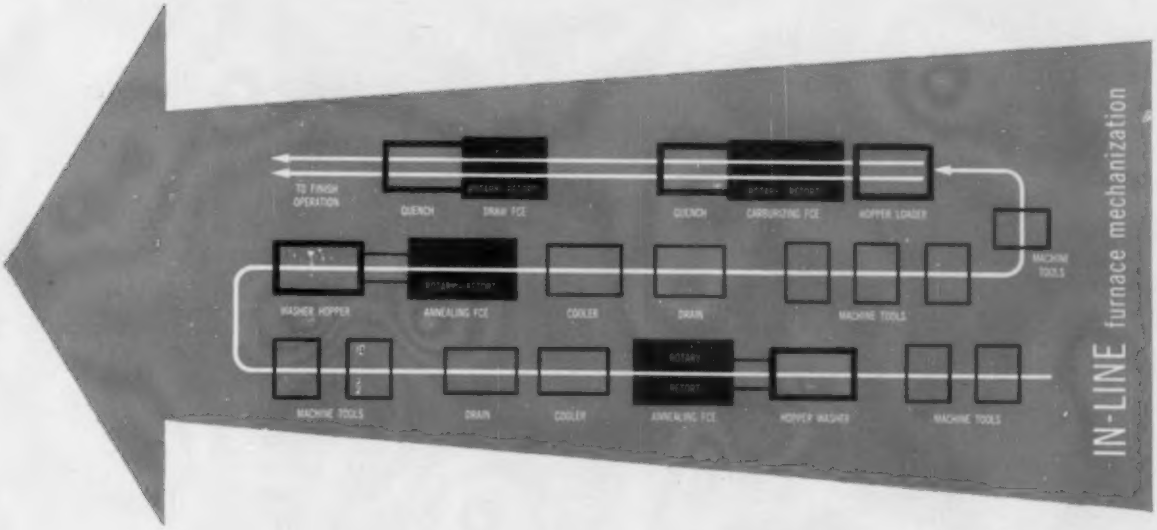





BATCH furnace mechanization
AUTOMATICALLY OPERATED DOORS
CHARGE MOVES AUTOMATICALLY TO AND FROM VESTIBULE
TO AND FROM FURNACE
AUTOMATICALLY OPERATED QUENCH ELEVATOR


IN-LINE furnace mechanization
TO FINISH OPERATION
QUENCH
ROTARY RETORT
DRAW FCE
QUENCH
ROTARY RETORT
CARBURIZING FCE
HOPPER LOADER
MACHINE TOOLS
WASHER HOPPER
ROTARY RETORT
ANNEALING FCE
COOLER
DRAIN
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RETORT
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HOPPER WASHER
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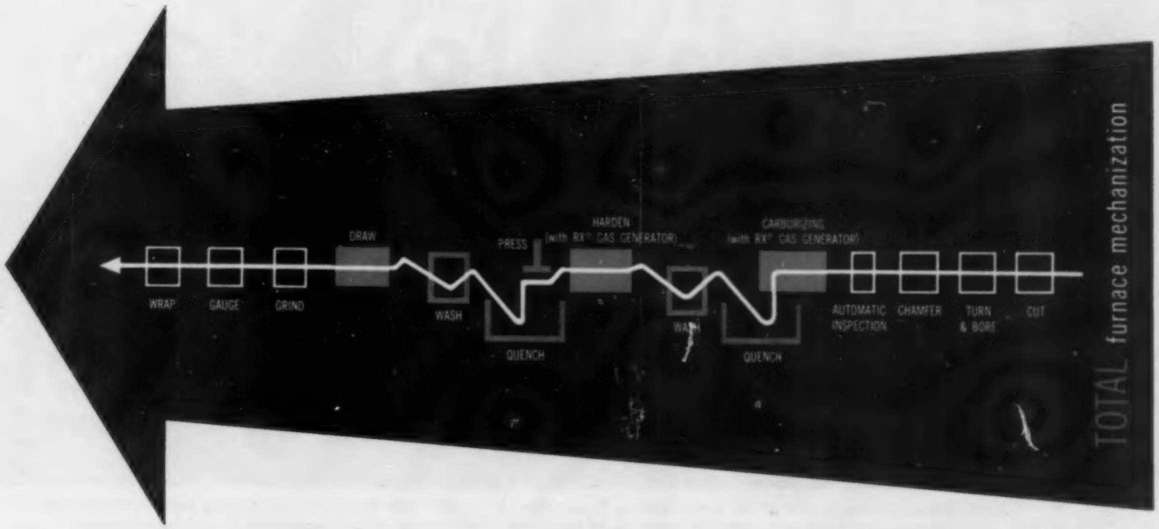
TOTAL furnace mechanization
WRAP
GAUGE
GRIND
DRAW
WASH
PRESS
QUENCH
HARDEN (with RX® GAS GENERATOR)
WASH
QUENCH
CARBURIZING (with RX® GAS GENERATOR)
AUTOMATIC INSPECTION
CHAMFER
TURN & BORE
CUT

F. G. Stengel, metallurgist at the Bettis Atomic Power Division, shown with the weld-conditioning box described on opposite page. He is examining the surface of a typical consumably-melted ingot prior to weld-conditioning.

METALLURGICAL PROCESS DEVELOPMENT

Weld-Conditioning of Reactive Metals for Nuclear Applications

This close-up shows ingots before and after new weld-conditioning process. Note the difference in surfaces.

A new weld-conditioning process for reactive metals used in nuclear applications has been developed in the metallurgical laboratories of the Bettis Atomic Power Division.

F. G. Stengel, Bettis metallurgist, first developed this process as part of a development program for the improvement of processes and techniques associated with fuel element fabrication problems. The process is designed to produce a sound and high-quality surface on ingots of materials used in reactor cores without sacrificing any appreciable amount of the expensive and critical alloys involved.

In this process, ingots of Zircaloy, hafnium, or uranium alloys are mounted inside a specially-designed weld-conditioning box. The apparatus must be vacuum-tight, because the materials being processed are highly reactive to the atmosphere. All of the driving mechanism (except the motor) is inside the box. Prior to weld-conditioning, the unit is evacuated and back-filled with helium or argon to slightly below atmospheric pressure. As the ingot rotates, a tungsten arc is struck against the ingot sidewall and the electrode traverses the length of the piece.

This remelts the surface of the ingot to a controlled depth, eliminating the porous, unsound peripheral layer and making it ready for immediate use to meet the demanding requirements of nuclear reactors.

Before this process was developed, the surfaces of these arc-melted or consumably-melted ingots were machined to remove this undesirable surface condition —or fabricated directly to strip and then conditioned in an attempt to improve the quality. These methods reduced yields and sacrificed up to ten per cent of the original ingot weight.

The weld-conditioning process as conceived by Mr. Stengel originally was applied to laboratory-size ingots weighing up to 30 pounds. But the process—including the size of the weld-conditioning box—has been expanded to include production-size Zircaloy ingots, weighing up to 1,000 pounds. Several of the commercial vendors who supply cladding material to Bettis use this same technique on the material they fabricate.

Mr. Stengel is a graduate of Massachusetts Institute of Technology, Class of 1952. He is presently assigned as a lead engineer to develop processes for the fabrication of fuel elements for a prototype reactor on the world's first atomic powered surface ship. And, like many of his associates, he is continuing his studies at the University of Pittsburgh, under the Westinghouse educational assistance program.

The weld-conditioning process described briefly on this page is only one of the many types of challenging projects which metallurgists encounter at Bettis—where you will find one of the highest concentrations of nuclear metallurgists in the country. If you are interested in working at Bettis with recognized leaders in the field of nuclear power, address your résumé to Mr. M. J. Downey, Bettis Atomic Power Division, Westinghouse Electric Corporation, Dept. A-182, Post Office Box 1468, Pittsburgh 30, Pennsylvania.

BETTIS ATOMIC POWER DIVISION

Westinghouse

Next Month—Metallurgical Materials Application—Application of More Economical Materials for Nuclear Power Plants

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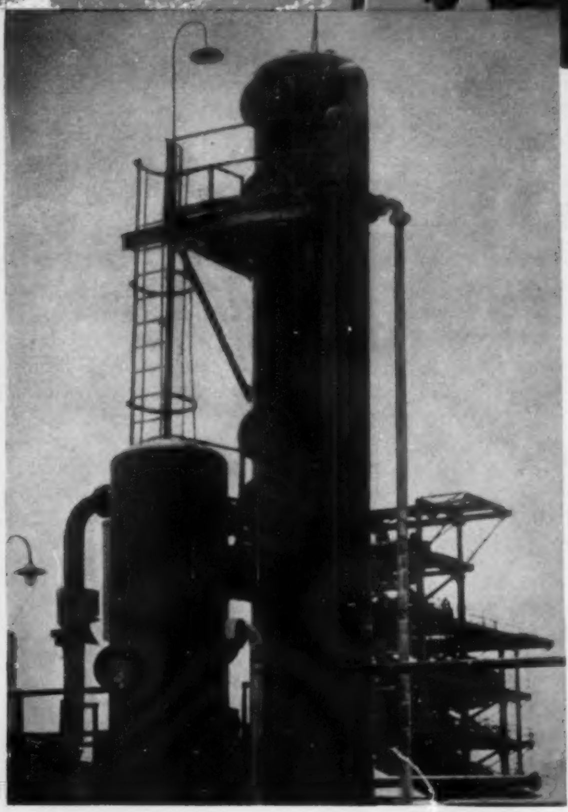

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In practically every industry, you will find HAYNES Alloys helping to increase production and reduce maintenance—doing an efficient job at low cost. For information on HAYNES Alloys, contact our nearest sales office or write HAYNES STELLITE COMPANY, Division of Union Carbide Corporation, General Offices and Works, Kokomo, Indiana. Sales Offices in Chicago, Cleveland, Detroit, Houston, Los Angeles, New York, and San Francisco.

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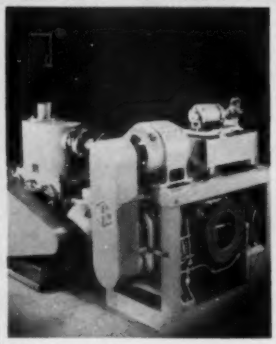

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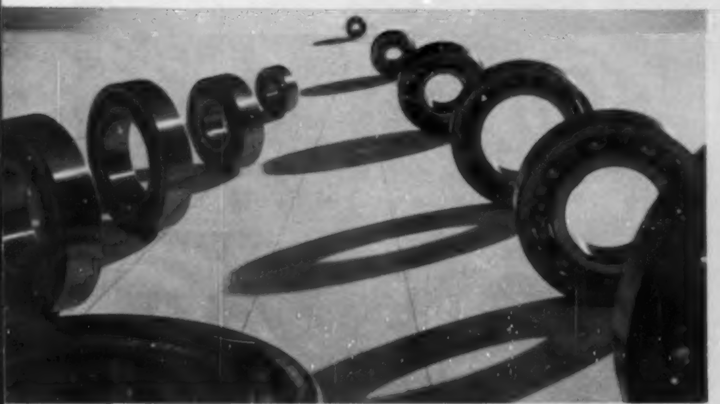

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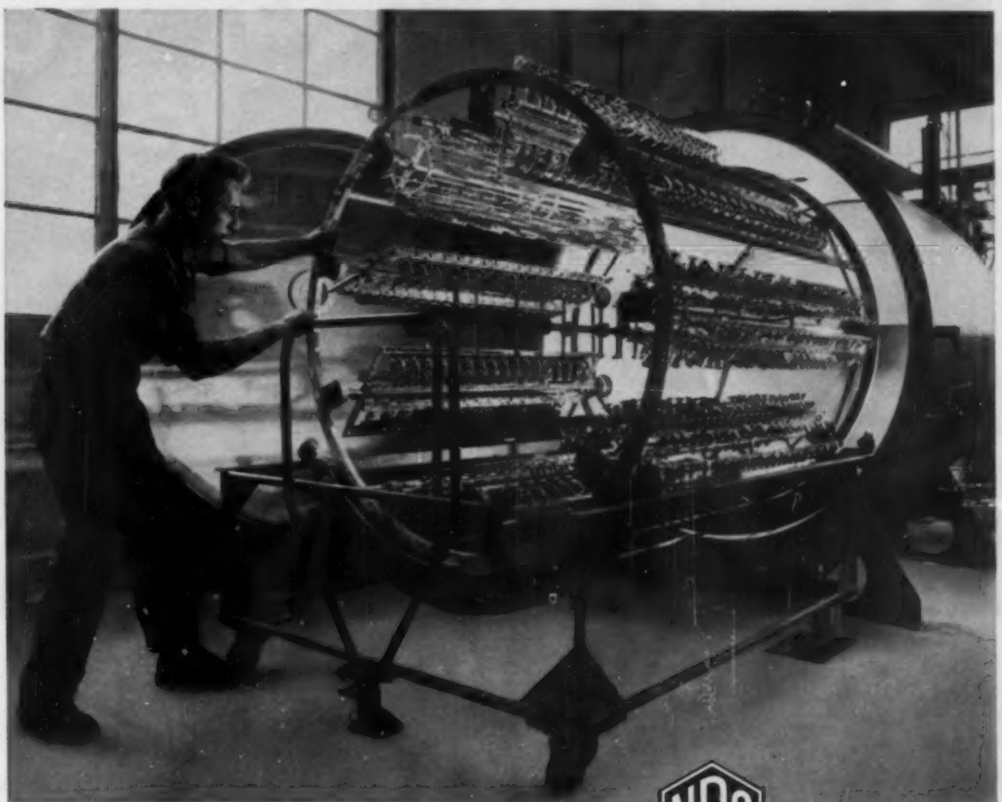

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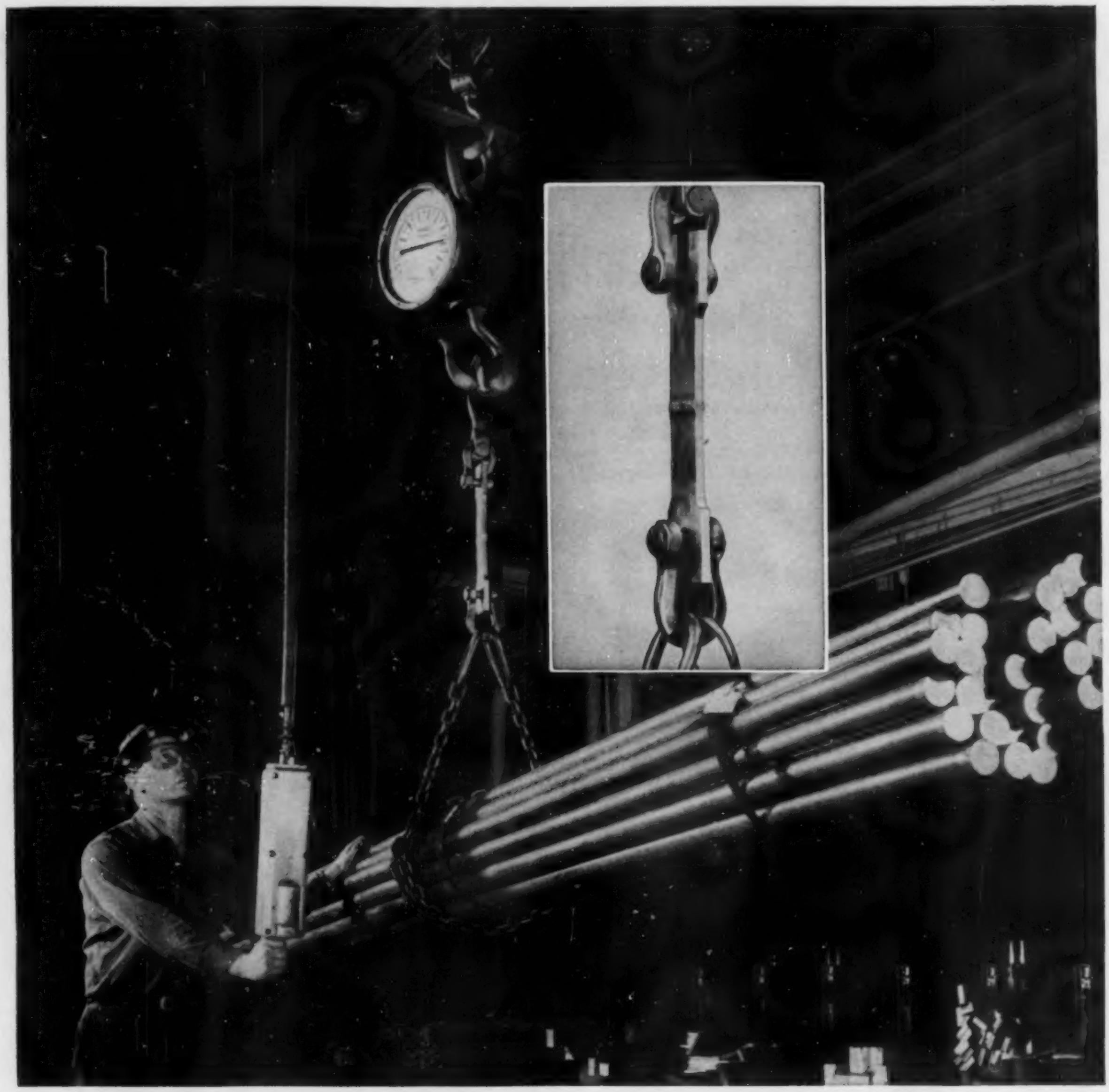

Weld Strength! Magnesium has 95% weld efficiency

In the picture above, a small arc-welded magnesium bar is supporting a load of four tons. This is one example of what we mean by "strong" when we say magnesium is light but strong. Its weld efficiency, the relationship between the strength of the parent metal and a welded joint, is very high. AZ31B magnesium alloy plate, tensile strength 35,000 psi, has a welded joint tensile strength of 33,000 psi, or a weld efficiency of 95%!

Magnesium can be arc welded, gas welded, or welded by electric resistance (spot, seam or flash). Magnesium plate ⅜" thick can be joined by arc welding in one pass. It can also be readily joined by most any other method: riveting, bolting, screwing, adhesive bonding and self-fastening devices.

These facts spotlight just one of the many reasons magnesium does a better job in many fabricated metal products. For more information, contact your nearest Dow sales office, or write to us. THE DOW CHEMICAL COMPANY, Magnesium Department, Midland, Michigan, Dept. MA1403Q.

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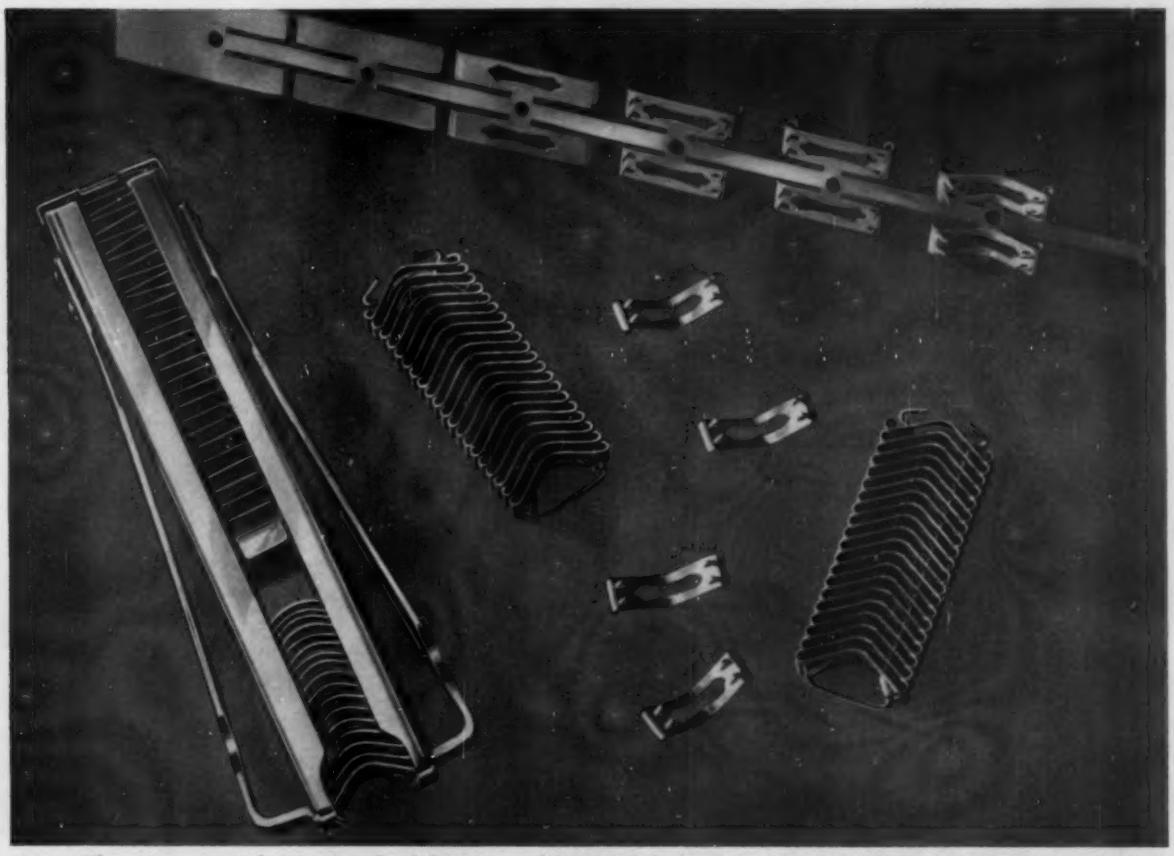

Above: The various steps in forming Autoclips® from Anaconda 18% Nickel Silver strip, .637" wide by .013" thick. Below are individual Autoclips and those mounted in wire holders ready for insertion in Autoclip Applier, at left. Exclusive wholesale distributor for Autoclip is Clay-Adams, Inc., New York City. ***Below, left:*** Autoclips being used to attach skin towel to edges of incision.

Anaconda Technical Service helped in

Selecting the exact Nickel Silver strip for this surgical clip

THE PROBLEM: The Technical Oil Tool Corporation, Los Angeles, developed Autoclip, an automatic magazine-type clip and applier to close wounds or incisions faster and easier. Selecting the right metal for the clip was the problem. A certain amount of tension was required to hold the wound edges together during healing, with the least amount of damage to tissues. In addition, the clip had to open easily for painless removal. The metal should be easy to form, and retain sharp, die-cut edges.

THE SOLUTION: After several unsuccessful attempts with various metals, sample clips of the required gage were made of Nickel Silver. These silvery white copper-alloys have excellent resistance to corrosion in service or in storage and have been time-tested for surgical instruments and equipment. Technical specialists of The American Brass Company suggested Nickel Silver, 18%-719—one of four standard Anaconda Nickel Silver Alloys—as the one best suited to meet all the requirements including tension, formability, clean edges and sharp points.

FREE TECHNICAL SERVICE: Metallurgists and technical specialists in The American Brass Company, through their day-to-day work with a great variety of metal problems, offer a tremendous breadth of experience. And this experience is at your disposal—to help you select the exact alloy, form, temper for your job. Call your American Brass Company representative, or write: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont. 5769

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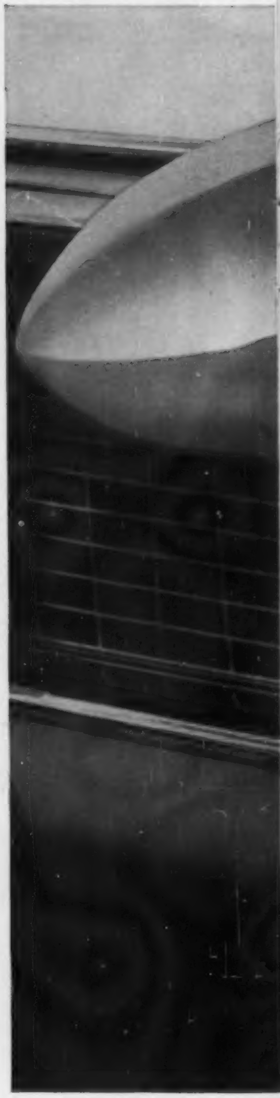


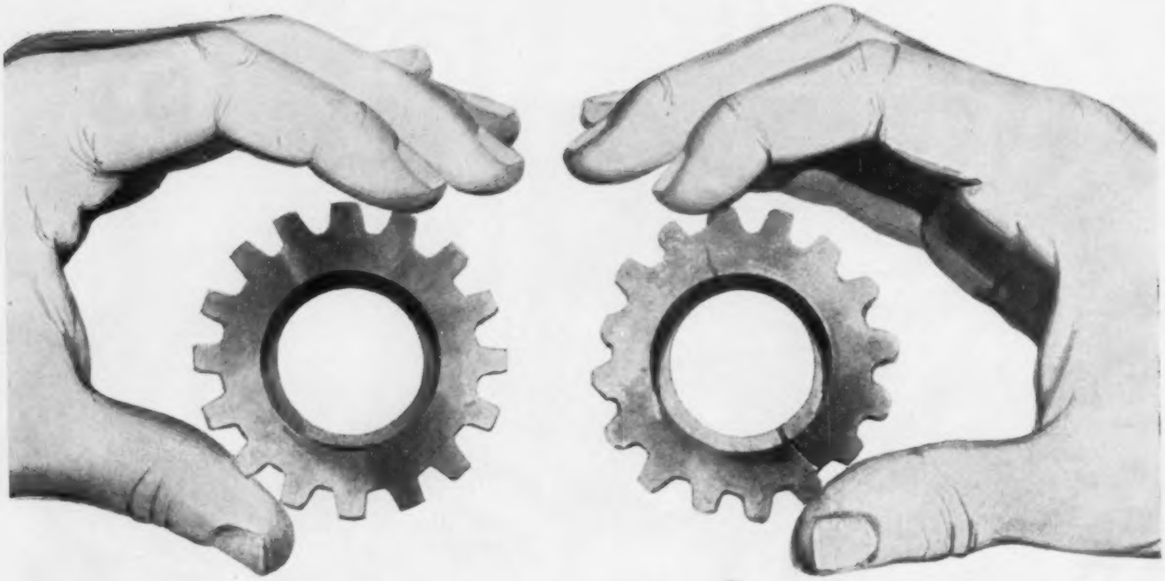
Among the many economical advantages of N-A-X FINEGRAIN—a low-alloy, high-strength steel with widely diversified applications in modern metals design—is its combination of great strength with excellent formability. Even at the higher strength levels (50% greater than mild carbon steel) N-A-X FINEGRAIN can be cold formed and drawn into difficult stampings and cold formed shapes.

Take these qualities and add the ability of N-A-X FINEGRAIN to be readily polished to a high luster at minimum cost, and when plated, you have a steel ideally suited for such applications as bumpers, bumper guards, and many others where strength and toughness with good finish is important.

Engineers and designers like N-A-X FINEGRAIN especially because its physical properties are inherent in the "as rolled" condition. No subsequent treatment is needed to insure its characteristics.

Check these other important advantages: N-A-X FINEGRAIN steel, compared with carbon steel, is 50% stronger • has high fatigue life with great toughness • is stable against aging • has greater resistance to wear and abrasion • is readily welded by any process • offers greater paint adhesion. NOTE: Where greater resistance to atmospheric corrosion is an important factor, our N-A-X HIGH-TENSILE steel is recommended.

For whatever you fabricate, from bumpers to bulldozers, with N-A-X HIGH-STRENGTH steels you can design longer life, or less weight, and economy into your products. Let us show you how.



"What's wrong? They're both 8620 alloy steel!"

A Baltimore manufacturer was working on an order for oil pump gears of 8620 alloy steel. The first lot of steel attained satisfactory core hardness—but the second lot would not meet minimum hardness requirements.

Both lots were bought from a reputable source. What went wrong?

The same alloy, sure—but different heats!

The manufacturer ran into trouble because the chemical composition and hardenability of different furnace heats of the same alloy can and do vary (within AISI and SAE limits) enough to have a marked effect on heat treatment response. As a result of such variation, the "right" alloy failed.

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Metal Progress

Volume 72, No. 2 August 1957

Furnaces for Sintering and Heat Treating Powder Metal Parts

*By N. K. KOEBEL**

Furnaces for sintering powder metal parts may be of mesh-belt, roller-hearth or mechanical pusher type, depending on requirements. The batch-type vertical radiant tube furnace is particularly suited for hardening sintered iron and steel parts in controlled atmospheres. (W26e, W27, 1-2; 6-22)

SINTERING FURNACES used for production of powder metal parts are somewhat similar to furnaces used for copper brazing. In fact, the furnaces may be used interchangeably, although certain fundamental principles of design must be incorporated in a sintering furnace that may not be necessary in a brazing furnace.

Generally speaking, in brazing, loads are lighter, parts can be brought rapidly up to temperature and need be held only long enough for the copper to melt. In sintering, parts must be brought to temperature at a slower and controlled rate of heating, and are then held for a soak period at the sintering temperature. A purge

*Director of Research and Manager, Lindberg Engineering Co., Chicago. Sequel to an article by Mr. Koebel in the May issue, p. 91, on "Atmospheres for Sintering Furnaces".

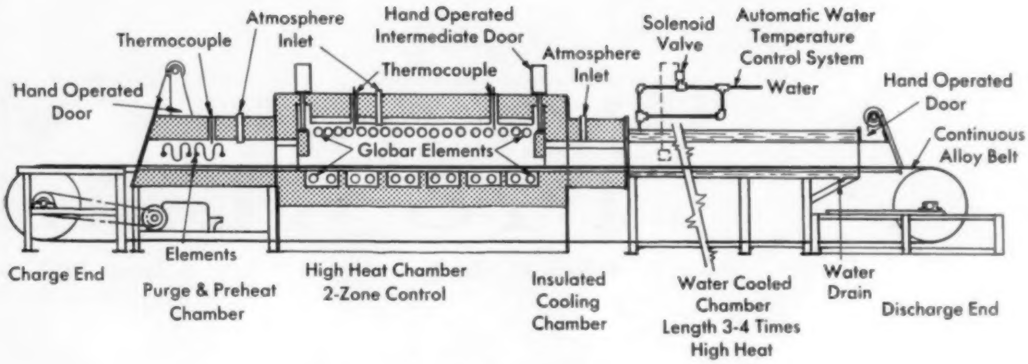


Fig. 1 – Mesh-Belt Continuous Sintering Furnace

chamber is essential to expel the air, the lubricant, and the binder entrapped in the voids of the powder metal compact before it enters the sintering chamber, so as to reduce contamination of the atmosphere.

Like brazing furnaces, sintering furnaces are usually heated electrically. Heating elements can be exposed to the protective atmosphere and it is easier to prevent leakage of the atmosphere by gas-tight shell construction than it is to use muffles or radiant tubes to keep the undesirable products of combustion separate from the protective atmosphere. Furthermore, at temperatures above 1850° F., which are necessary for sintering some materials, the efficiency of a gas-fired muffle or radiant tube furnace is low and the maintenance is high. In the lower range – up to 1650° F. for brasses and bronzes – muffle or radiant tubes can be used in sintering furnaces.

Thus, the essential principles in construction of a sintering furnace are (*a*) a gas-tight furnace, (*b*) a purge chamber to expell the air, lubricants, or binder vapors, (*c*) a controlled rate of preheating, (*d*) a controlled high-heat sintering chamber, and (*e*) a water-jacketed cooling chamber with a protective atmosphere to prevent oxidation.

A controlled rate of preheat and high heat is essential to control the final dimensions of the sintered compact. If a pressed compact is heated too fast, there is a tendency for the entrapped air or lubricant to expand rapidly and thus push the metal particles apart. The denser the compact, the greater is this tendency. Whatever heating rate is established, it must be under control at all times.

Choice of furnace design depends upon the sintering temperature, the material to be sintered, the sintering atmosphere, the production, and the operating and maintenance cost for a given production. Various types of sintering furnaces

Fig. 2 – Mechanical Pusher Sintering Furnace

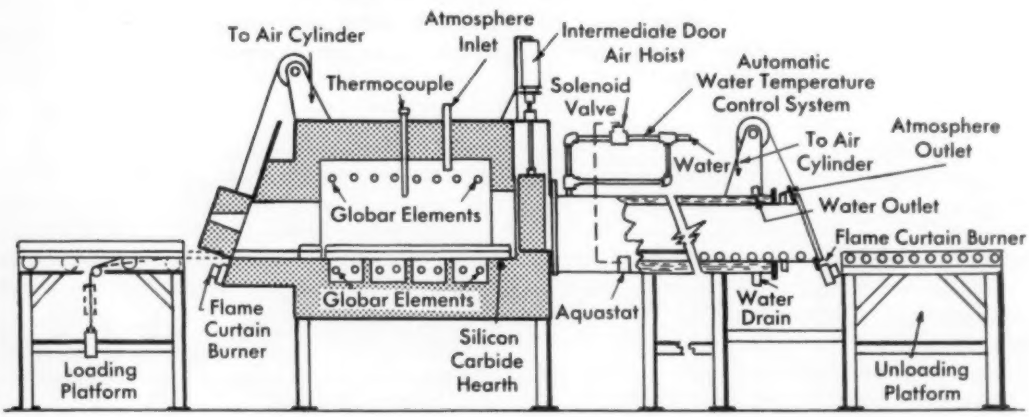
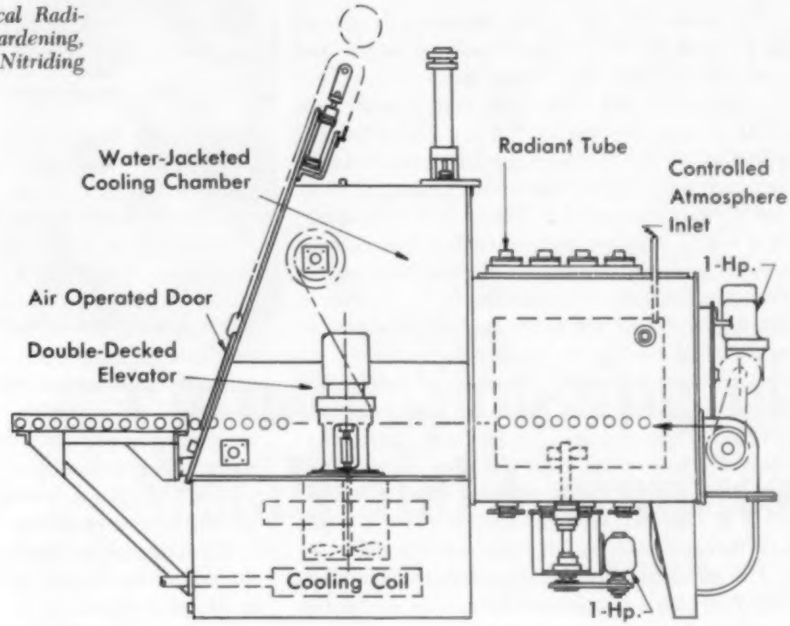


Fig. 3 – Gas-Fired Vertical Radiant Tube Furnace for Hardening, Carburizing and Carbo-Nitriding



will now be described and their proper applications pointed out.

The mesh-belt conveyer furnace is one of the most commonly used sintering furnaces for continuous production of small, light parts in copper, brass and iron. As shown in Fig. 1, it consists of a charge table for loading the parts on the belt, a purge and preheat chamber automatically controlled to distill off the lubricants and binder, a heating chamber generally with two zones of automatic and independent control, an insulated cooling chamber, automatically controlled water-cooled chambers, and a discharge table. A variable speed drive permits adjustment of belt speed to meet the heating requirements of the work being treated. The heat resistant alloy belt limits the operation of the furnace to 2100° F. At high temperatures – 1850 to 2100° F. for iron or steel parts – the load on the belt is limited to 10 to 12 lb. per lineal ft. At 1650° F. – generally used for bronze and brass – the load can be increased to 25 lb. per lineal ft. Production rates up to 400 lb. per hr. can be handled.

Heating elements may be either silicon carbide or 80-20 nickel-chromium alloys. The nonmetallic silicon carbide elements are necessary for high-temperature operations on iron and steel powders, whereas at the lower temperatures (1850° F. max.) used for sintering copper, bronze, and brass, the metallic elements are suitable. The silicon carbide elements are necessary with an atmosphere of high carbon potential such as used to prevent decarburization of iron sintered above 1850° F., whereas the Ni-Cr elements in this atmosphere will carburize and have short service life.

The silicon carbide heating elements also offer greater protection against other sources of contamination, such as carry-over of the zinc stearate lubricant into the high-temperature zone, deposition of carbon on the heating elements, and zinc, lead, and copper that may distill off the compacts being sintered. The carbon deposited on the silicon carbide resistors by stearate carry-over will eventually cause the resistors to draw more current, but this can be seen on the ammeter of the transformer and the voltage to the resistors can easily be dropped by setting the transformer to a lower voltage tap until such time as the carbon is burned out of the furnace. With the metallic resistors, the carbon deposit is likely to short out between turns on high-potential leads, causing a failure.

Since most manufacturers work with both ferrous and nonferrous parts, the silicon carbide resistors are generally selected.

The roller-hearth continuous sintering furnace is similar to the conveyer-belt furnace except that the parts are loaded into trays, and the trays are conveyed through the furnace by riding on

driven rolls. The doors are automatically opened and closed by air or motor and are interlocked with the charging and discharging cycles. Like the mesh belt, the alloy rolls limit operation to 2100° F. max., but each roll is capable of holding a load of 35 lb. If a load can be suspended over two rolls a foot apart, maximum loading is 70 lb. per lineal ft. compared to 7 to 10 lb. for the mesh-belt type. Another feature is that this furnace can be made in any length to meet the production requirements, whereas the belt conveyer is limited by the stretch of the belt which increases as the total load in the furnace increases.

Roller-hearth furnaces are built to handle 500 lb. per hr. and upward. They are useful not only for heavy parts but also for high parts that require a large door, since the doors on a roller-hearth furnace are only opened when a tray of work is charged, whereas the doors on a mesh belt furnace must be left open continuously.

The mechanical pusher-type furnace, shown in Fig. 2, is also a continuous furnace in which the parts are loaded on trays, but the trays are mechanically pushed through the furnace instead of rolled. Heat resistant alloy trays are used up to 2100° F., and ceramic or graphite trays for higher temperatures. Globar nonmetallic heating elements are normally used for operation up to 2500° F., and molybdenum heating elements in a hydrogen atmosphere for temperatures above 2500° F.

Two types of pushing mechanisms are generally employed – the intermittent and the continuous stoker. The intermittent pusher is usually used with bronze, brass, and iron powder parts, and the continuous stoker type for sintering carbides in the high-temperature molybdenum resistor furnace.

The mechanical pusher-type furnace is particularly suited for sintering metal parts that are too heavy for the mesh-belt conveyer yet the production rate does not warrant the roller-hearth furnace, and also for sintering at temperatures too high for an alloy belt or alloy roller. They are available for production loads up to 600 lb. per hour.

Where production does not warrant continuous operation, such as on the smaller furnaces used for low production runs or for experimental purposes, the pusher mechanism can be eliminated and the work pushed through by hand. Special small muffle furnaces with gas-tight interlocks for charging and discharging are also used for stainless steels or Alnico where the hydrogen atmosphere must be controlled to an extremely low dew point.

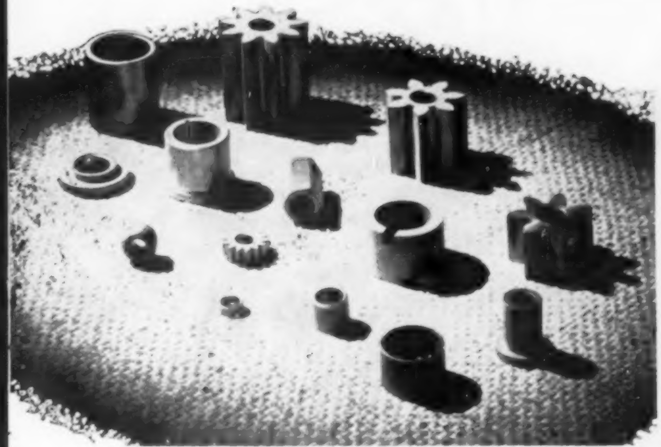
Hardening Furnaces

Iron and steel powder metal parts are often heat treated after sintering. The strength and hardness of medium and high-carbon iron parts can be increased by heating to 1500 to 1650° F. (depending on the carbon content) and quenching in oil. Low-carbon iron powder parts can be case hardened by carbo-nitriding or carburizing followed by an oil quench. Atmosphere methods are almost universally used because salt tends to be absorbed into the pores of the part, lowering its corrosion resistance. Best case hardening results are obtained on powder metal parts having a density of 7.4 g. per cc. or higher, which will give a well-defined martensitic case similar to that produced on wrought steel.

The atmosphere used for case hardening is of the endothermic type described in the May issue of *Metal Progress*, p. 91, adjusted to a high carbon potential of 20° F. dew point with 5 to 10% natural gas added to increase the carburizing potential. To obtain a case similar to that produced by cyanide, a carbo-nitriding atmosphere is provided by adding 5% natural gas with 10% ammonia to the endothermic carrier gas. If the part is composed of medium or high-carbon iron powders, the dew point of the endothermic atmosphere is adjusted to the carbon content of the part as shown in the equilibrium diagram in the May issue, p. 98.

The batch-type, vertical radiant tube furnace shown in Fig. 3 is ideal for neutral hardening, carbo-nitriding, or straight gas carburizing. It can also be furnished electrically heated with the newly developed "Corrtherm" resistor. It can be either completely automatic or hand-operated.

The work is charged into the purge and quench vestibule by hand. In the automatic furnace, the work is carried into the furnace by a mechanical pusher. At the end of the heating cycle, the work is discharged automatically from the furnace onto the quench elevator. After quenching for the proper interval as set by automatic timers, the work is raised automatically and a signal tells the operator to pull the tray out of the purge chamber. While one tray of work is in the quench tank, another is charged automatically into the furnace. Since the work does not contact the air until completely heated and quenched, the part stays bright and free from scale throughout the entire cycle.



Furnace Sintering of Metals and Ceramics

By R. L. HARPER*

Brief notes on temperatures, times and atmospheres for the well-known powders, plus remarks on reasons for vacuum sintering, the handling of mixtures for magnets and electronic "ferrites", as well as the metallizing of ceramic bodies so connections can be welded or soldered thereto. (H15, W26e, 1-2)

SINCE THE TITLE of this paper covers a great deal of territory – metals, oxides, carbides, borides, and intimate mixtures or adherent coatings, all starting from powders – any short treatment must confine itself to a single aspect. In this instance it will be a brief description of the furnaces, atmospheres and temperatures for sintering the compacts, with a few remarks about special techniques. The discussion will be subdivided according to the material to be heated.

Copper, brass and bronze powders are used to make such structural parts as gears, bearings, lock parts, many small machine parts, and porous filters – to name a few. The atmosphere is usually dissociated ammonia. Bronze powders are sintered in the temperature range of 1400 to 1600° F. and require from 10 to 20 min.; copper powders from 1550 to 1650° F. for 30 to 45 min. Bronze powders of the 80-20 type require from 1550 to 1650° F. and 30 to 45 min. is needed for proper sintering.

The parts are usually small and are arranged on trays and put through continuous furnaces of the pusher type. In small furnaces the operator can use a poker to push the trays through the hot zone and out into the water-jacketed chamber for cooling. Such a furnace would have an alloy muffle which contains the hydrogen-nitrogen atmosphere required for bright sintering. A small ammonia dissociator will produce about 150 cu. ft. per hr. of gas which is continuously admitted to the furnace to purge out the impurities brought into the furnace with the charge, to carry off any fumes which are given off by the

*Executive Vice-President, Harper Electric Furnace Corp., Buffalo, N.Y. Paper presented at the 10th Western Metal Congress held in Los Angeles, March 1957.

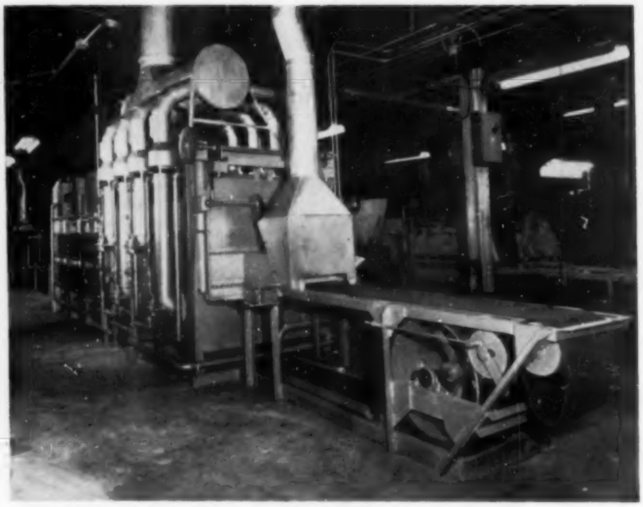


Fig. 1 – Entrance End of Continuous Furnace With Wire Mesh Conveyer for Sintering Iron Compacts. The furnace has three zones: gas-fired preheat, electrically heated sintering zone, long cooling chamber for slow cooling

hot product, and to sweep out any air which comes in through the doors.

More difficult is the sintering of porous metallic filters – a product whose use has increased tremendously – and for this process a continuous mesh-belt furnace will serve nicely. One simple expedient, often noted, is to place a small cover of heat resistant sheet metal over small groups of parts as they are placed on the entrance belt. These covers check rapid air cooling just after the work leaves the exit door and often prevent a slight oxidation.

Iron – Many parts are now made of powder iron, as illustrated by samples in the photograph at the head of this article. Such parts require a little higher temperature than copper, namely from 1850 to 2100° F., and the work should remain in the hot zone 30 to 45 min. This means a larger or longer furnace, if much production is required. High-carbon and alloy powder compacts are usually heated in a rich endothermic atmosphere, while low-carbon steels require an atmosphere of low hydrogen content, so they may be heated in a lean endothermic atmosphere.

The present trend in furnace design is to place a presintering section ahead of the high-temperature zone. Figure 1 shows a mesh belt furnace with a gas-fired presintering furnace ahead of a high-temperature final sintering section heated with nonmetallic electric resistors. This heats the compacts gradually and drives off the carbonaceous binder slowly, a practice which gives closer dimensional control of product and eliminates blistering. Furnaces of this general type are available with both electric and gas-fired preheat sections.

Infiltration – Copper infiltration of iron parts can be done in mesh-belt, pusher-type, or roller-hearth furnaces. The process consists of placing a small piece of copper in the top of an iron part presintered in protective atmosphere so it is free of oxide, both internal and external, and retaining considerable porosity, and passing it through a furnace at 2100° F. – a temperature at which the copper readily melts and is drawn into the pores of the iron part. Hydrogen atmosphere is usually used – either pure hydrogen or dissociated ammonia.

One advantage of a roller-hearth furnace for this process is that it can be quite long so that a long soak period and high production can be obtained where necessary.

Stainless Steel – Manufacture of parts from stainless steel powders has created considerable interest recently. They require relatively high temperatures, in the range of 2150 to 2300° F., and a very dry hydrogen atmosphere or dissociated ammonia, with a dew point in the neighborhood of −50 to −80° F., even in the cooling chambers. Inconel muffles are very satisfactory in the hot zones to maintain the very pure dry hydrogen.

Stainless steel parts have been successfully sintered in mesh-belt furnaces where the entrance and exit ends are lower than the center section – a type called a "hump" furnace, which is applicable to parts of such shapes that they can move up and over the hump without tipping over. Pusher-type furnaces used for this same work would have purge chambers at both ends where the space is carefully purged of oxygen and then filled with pure dry hydrogen before

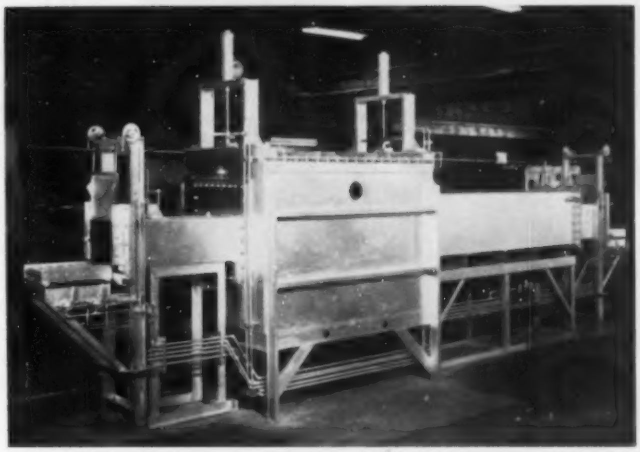


Fig. 2 – Exterior View of Three-Compartment Furnace for Sintering Carbide Compacts at 2650° F. Muffle is of alundum, heating elements are of molybdenum. Work and heaters are both protected by dry hydrogen

the door leading into or from the furnace chamber is opened and the charge moved through.

Alnico – The sintering of alnico magnets (Ni-Al-Co with Fe) requires a temperature of 2200 to 2375° F. and needs 2 to 2½ hr. for the process. It is also done in pure dry hydrogen. These temperatures are quite high and involve changes in furnace design which do not appear on the outside. For example, the muffle might be of alundum (Al_2O_3 refractory), wound with heavy molybdenum wire and isulated with alundum powder. The molybdenum wire itself must be carefully protected from oxygen while it is hot. Sometimes a smaller iron muffle is placed inside the alundum muffle.

Carbides – Compacts of carbides of molybdenum and tantalum are often presintered or partially sintered, in which state they can be machined to final size plus small shrinkage allowance, after which they are fired in a hydrogen atmosphere. Final sintering is done in a fairly large furnace, heated with molybdenum elements (Fig. 2). The carbide compacts are usually placed in graphite boats, packed with carbon, and passed through the furnace at 2600 to 2700° F., and held at temperature from 20 to 30 min. As stated above, the molybdenum heating elements must be protected with hydrogen. After sintering, the boats are pushed into the water-cooled chamber and cooled sufficiently so that they can be drawn out into the air without oxidizing the graphite boats.

Vacuum sintering is becoming very important in many processes. Vacuum sintering is usually done where hydrogen – probably our best protective gas – will embrittle the product being sintered. This is especially true of titanium, in which temperatures are not unusually high. Various materials are used for the retort. For low-temperature vacuum annealing, Inconel tubes can be used; for higher temperatures, porcelain or quartz. The operation is a batch process in which the parts are placed in a muffle, a surrounding tank closed and evacuated, heat applied inductively either to the charge or surrounding muffle, and the vacuum pump operated during the entire cycle.

At the present time, vacuum sintering furnaces have been used mainly for special applications involving the highly reactive metals such as titanium and zirconium, for atomic reactor components and corrosion resistant parts for the chemical industry. It should be mentioned, however, that they are frequently used for carbide sintering.

The main reason for using a vacuum is to insure that the compact is completely outgassed so that no oxide can be formed on the inside; in addition, the need for expensive atmospheres is eliminated.

Roll Bonding – A very new application now being seriously considered is the continuous furnace sintering of titanium powder into strip. This process would bypass many of the steps used in the standard method of producing titanium sheet.

Another new development that has not been mentioned too often is roll bonding, as described by Samuel Storchheim in *Metal Progress* for September 1956. The indications are that sheets and bars of many metals will be rolled from powders, then sintered, re-rolled and annealed – repeating the process several times until a sheet or bar has been obtained having physicals

Fig. 3 – Car-Type Furnace for Sintering "Ferrites" Used in Quantity for Electronic Gadgetry

equivalent to the corresponding products wrought from cast ingots. On a large-scale basis, this particular application is very attractive, since considerable scrap can be used to produce the powder and there should be very little loss of metal in process.

"Ferrites" – So far we have limited the discussion to furnaces and processes for sintering metals. Now let us turn to the sintering of the unusual materials called "ferrites". Ferrites are a blend of iron, iron oxide and compounds (oxides, hydroxides, carbonates) of zinc, nickel, manganese, magnesium, cobalt, copper and other metals. They are compacted into parts for radio, television and other electronic equipment. They can also be formulated to produce a very fine permanent magnet which can often be used in place of the well-known alnico magnet.

Some ferrites are sintered in an air atmosphere; others are sintered in a neutral atmosphere with controlled amounts of oxygen. In general, the sintering operation is much like that for other powdered materials. A temporary binder is driven off during the early stages of heating at 700 to 900° F.; then the product is brought up to a temperature of 2300 to 2400° F. at which it will sinter, and is held for the required length of time. Cooling of the product is sometimes very rapid and often at a controlled rate to obtain the required electrical characteristics.

A typical ferrite application is "memory rings", which are used to store miniature electrical charges in digital computers. These tiny parts are placed on trays, passed through the furnace continuously, gradually heated to the sintering temperature, held very closely at temperature at the center of the furnace, and finally cooled gradually. The furnace therefore has three zones of temperature control. (If electrically heated, the transformers may be mounted below the furnace under each of these zones.) A variable speed drive pushes the charge through the furnace, and a small venturi fan draws the atmosphere counterflow to the charge, drawing off the volatiles that are vaporized in the preheat section.

Larger ferrites, such as "C cores", yokes, antenna rods and rings used in radio and television, are usually sintered in car-type furnaces. Furnaces are of various sizes, from the small one shown in Fig. 4 (where the items are placed on trays, stacked one above the other and pushed through the furnace), to very large units where a great many pieces are sintered at one time on a car top.

Some sintering of ferrites is done in periodic furnaces such as small elevator-type furnaces with an individual car. In such a furnace the atmosphere can be maintained at the desired oxygen content and the product can be heated very uniformly and gradually, held within very close temperature limits during the sintering operation, and then cooled within the furnace.

Really High-Temperature Work – One of the newer materials which we will hear more about is uranium oxide. For sintering this requires a very high temperature – 3000 to 3200° F. – and a hydrogen atmosphere. The product must be held at temperature for several hours. A furnace for doing this work is normally equipped with purge chambers at both ends (so the hydrogen atmosphere can be maintained dry) and uses heavy molybdenum rods for heating elements.

Metallizing of ceramic parts is important to the television and tube manufacturing industries. Various alloys are sintered on alundum refractories, thus forming a surface to which various metals can be soldered and brazed. For this purpose a molybdenum-manganese alloy is one of the numerous alloys used. To furnace-sinter these metals on the alundum parts, they are pushed through pusher-type furnaces so the product is heated gradually to a sintering temperature of about 3000° F. in a hydrogen atmosphere.

Foundry Metallurgy

*Reported by ALFRED H. HESSE**

American Foundrymen's Society hears that aluminum castings can be improved by sharply limiting the iron content. Die castings, vacuum melted, may compete with stampings. Graphite is, so far, the only practicable mold material for titanium. Tin (up to 0.10%) seems advantageous to gray iron – contrary to its popular reputation. Calcium is also the preferred element for inoculation of gray cast iron. (E General)

CINCINNATI was host to the 61st A.F.S. Castings Conference early in May. The perennial problem – improvement in quality – was discussed from many viewpoints. Perhaps elimination of surface defects got the most attention. A close relative is the problem of accurate size, so as to minimize or even eliminate machining costs. The constant demand for improvement in mechanical properties, soundness, and for alloys that withstand relatively high temperatures, brought forth a number of papers of prime interest to metallurgists.

Light Metals

Aluminum – Tensile strength of aluminum alloy HP 356 can be raised 10,000 psi. (from 35,000 to 47,500) by limiting the iron content to 0.15%, according to Allen B. DeRoss, technical specialist, Kaiser Aluminum and Chemical Sales, Inc., Chicago. Such an improvement may be expected to extend the structural applications; the alloy is now used extensively for aircraft fittings, pump parts, automotive cylinder blocks and transmission parts. It has excellent castability, producing pressure-tight castings with good corrosion resistance. The previous limitation on the regular 356 aluminum alloy is 0.50% iron, and to keep it down to 0.15% requires extreme care in melting to avoid contamination. The difference in the iron content appears to be the crux of the situation. Aircraft and automotive parts can possess added strength (without an appreciable loss in ductility) which is an important weight saving on some castings.

Another bad influence of iron in another family of alloys was brought out in the paper "Corrosion of Aluminum Die Castings" by Donald L. Colwell and R. J. Kissling of Apex Smelting Co., Cleveland. They find that the aluminum alloys No. 13 and 43 have superior corrosion resistance and the silicon-magnesium alloy No. 36 has inferior corrosion resistance in alternate immersion tests in a salt solution. The iron content should not exceed 1.3% in No. 36 aluminum in order to obtain the best corrosion resistance; zinc up to 2 or 2½% has no harmful effect.

G. W. Stickley and G. L. Miller of Aluminum Co. of America, Pittsburgh, reported on the fatigue properties of two aluminum die casting alloys, 218 and 380. While they are about the same at 70° F., 380 alloy is generally superior to 218 at elevated temperatures. Slight notches have a detrimental effect on fatigue strength of either in repeated bending or under fluctuating axial stresses; this effect is larger for sharper notches and at larger numbers of cycles of stress, but becomes smaller at elevated temperatures. Alloy 218 contains 8% magnesium and has a good

*Metallurgical Engineer, R. Lavin & Sons, Inc., Chicago.

combination of high strength and ductility, together with desirable resistance to corrosion and adaptability to protective chemical finishes. Alloy 380, containing 8.5% silicon and 3.5% copper, has high strength and is considerably easier to cast.

Vacuum Melting for Die Castings

According to David Morganstern of Nelmor Mfg. Co., Euclid, Ohio, a vacuum die casting process has produced zinc and aluminum castings commercially with properties comparable to nonferrous forgings. He also thinks that wall sections can be so sharply reduced without losing strength that the cost of such die castings may become competitive with stampings. (Previously wall sections in zinc ran from 0.050 to 0.070 in. and in aluminum from 0.080 to 0.100 in.) Furthermore, aluminum castings, vacuum melted, can now be anodized to give a durable, clear finish, formerly unattainable, for the reason that such aluminum alloys are run without the addition of silicon. The economics of die casting are also improved by an increased speed of operation. An example of the improved mechanical properties of a zinc alloy die casting was given. Six tensile tests from conventional die castings averaged 36,100 psi. while those from vacuum die castings averaged 42,866 psi.

New Copper-Nickel Alloys – A new high-strength and corrosion resistant cupronickel alloy, designed for service in marine and power installations, was reported by G. L. Lee of International Nickel Co., New York City. It was found that an alloy containing 12% Ni, 1.5% Al, 1% Mn, 0.6% Fe, balance Cu – deoxidized with 0.05% each of phosphorus, titanium, and calcium in calcium-silicon alloy – will have a tensile strength of 95,000 psi. and is suitable for pressure and structural castings under severe marine corrosion. Elongation of approximately 10% was reported. Ample gating and risering practice along with nonturbulent handling of the metal was necessary with this aluminum-containing alloy to produce sound, pressure-tight castings. Lead has been found to lower the mechanical properties as much as 30% and should be kept out of bronzes deoxidized with silicon; hot shortness and cracking occur when lead is over 0.1%.

Another copper-base alloy containing 12% Ni, 1% Mn, and 1.2% Fe has a tensile strength of 45,000 psi. and elongation of 30%, and is suitable for pressure castings. It was emphasized that these are as-cast properties and that corrosion tests in sea water show both these alloys to be superior to the more commonly used bronzes.

Castings of Titanium Alloys – A session early in the convention was devoted to titanium, and it drew a good audience. Speakers were quite hopeful that such alloys were able to meet some of the most severe demands required by the aircraft, chemical and marine industries. Chemical processing plants are now using some titanium-base alloy for vital parts requiring highest corrosion resistance to difficult chloride solutions. Low density, 40% that of stainless steel and only 1.6 times that of aluminum, combined with tensile strength at 70° F. as high as 140,000 psi. in the as-cast condition, gives titanium alloys the outstanding strength-weight ratio needed for airborne craft. One of the main problems which the foundryman faces is the fact that molten titanium is extremely reactive, not only with atmosphere but with most refractory materials.

According to A. L. Feild, Jr., of E. I. du Pont de Nemours & Co., Inc., and R. E. Edelman of Frankford Arsenal, difficulties of casting molten titanium can be minimized by using an expendable molding material based on graphite powder. Using this with conventional molding processes, a 1½-in. valve body was successfully cast of unalloyed titanium without contamination. The core was made of the same material. Results appeared to be satisfactory, although two important problems remain – namely, processing problems associated with high water content and a poor surface finish. Mechanical tests indicate excellent ductility and machinability. The surface hardened layer does not exceed 0.020 in. in depth or a hardness of 300 Knoop. Internal cores present no reaction or knockout problems.

A paper on "Status of Technology for Casting Titanium" was presented by G. H. Schippereit, R. M. Lang and J. G. Kura of Battelle Memorial Institute, Columbus, Ohio. Machined graphite molds were found to be satisfactory; unfortunately they are very costly. Copper molds have longer life than graphite molds but are even more expensive and have stronger chilling effect. The use of expendable graphite inserts was one suggestion, and an oxygen-deficient zirconia was discussed as another solution. The latter was reported to shrink between 15 and 20%; this will present some difficulty in the reproduction of mold cavities of specific dimensions.

The authors report that cast titanium and titanium alloys have strengths approaching those of wrought items. Their ductility, however, is somewhat lower.

Consumable electrode furnaces with "skull-

type" crucibles are said to be best for casting titanium. Similar furnaces melting alloy under an arc struck from nonconsumable electrodes have difficulty in providing adequate superheat before casting; there is also the danger that the electrode will contaminate the melt. Carbon contamination and associated low ductility confront those using graphite crucibles in an induction melting furnace. A high-intensity electrical field which piles the melt in the center of the graphite crucible resulted in a less than 0.15% carbon content in a 5-lb. heat prepared by the induction melting process.

"Mechanical Properties of Cast Titanium-Iron and Titanium-Aluminum-Iron Alloys" by N. Hehner, H. W. Antes and R. E. Edelman of Frandford Arsenal, Philadelphia, reported that tensile strength increased and the notched-bar impact strength decreased with increasing iron content up to 6%. As aluminum was increased in the titanium-iron alloys, the strength was increased still further. Elongation and V-notch Charpy values decreased as the tensile strength increased. The authors judged the alloy with 1% Fe and 3% Al to have the best combination of tensile strength and ductililty as well as impact strength. At 212° F., the impact strength of this alloy was about 48 ft-lb. and at –70° F., it was about 32 ft-lb.

Gray Iron

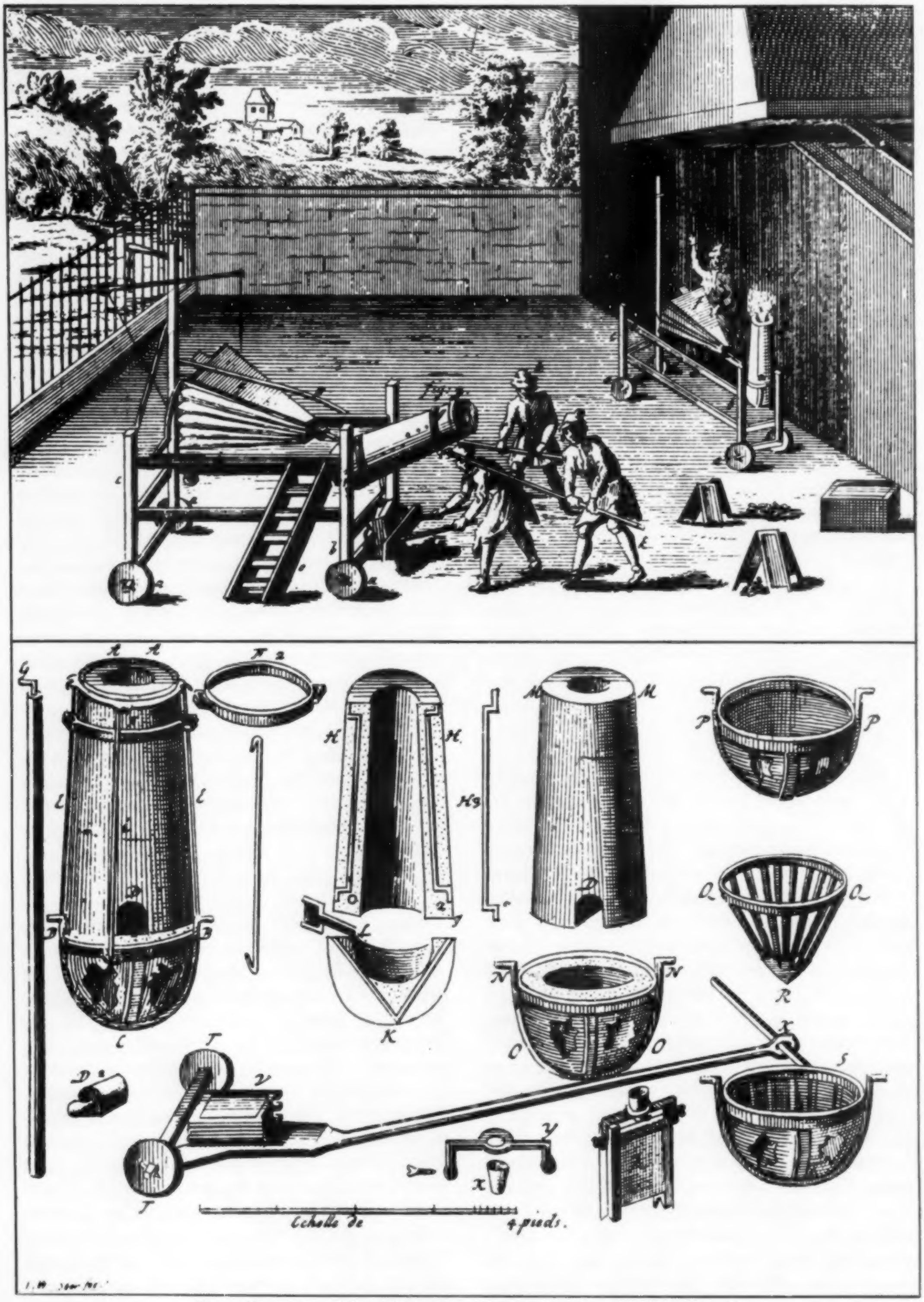
The effect of tin in gray iron was reported by J. A. Davis, D. E. Krause and H. W. Lownie, Jr., of Gray Iron Research Institute, Columbus, Ohio, in a paper entitled "Tin Is Not a Subversive Element in Gray Iron". Contrary to the almost universal supposition, tin up to 0.10% resulted in slightly improved mechanical properties without producing any undesirable casting effects. Not only were no embrittling effects found up to levels of 0.10% Sn, but in this range tin has a major beneficial effect upon the microstructure. Investigations on cast irons melted in a laboratory and on irons melted in cupolas in commercial foundries agree that additions of tin had a powerful stabilizing effect on the pearlite in the microstructure of both automotive type, hypo-eutectic and general-purpose hypereutectic irons. Tin used for such stabilization did not show the objectionable tendency to promote chill depth which is associated with other alloys commonly used for the same purpose. Also on the favorable side, the researchers found that a substantial excess of tin did not cause massive iron carbides to form in the matrix.

An exchange paper by G. N. J. Gilbert of the British Cast Iron Research Assoc. was entitled "Temper Embrittlement in Nodular Cast Irons" and showed how the cooling rate affects the ductility of iron. For instance, ferritic nodular cast irons and malleable cast irons of appropriate composition, which have previously been slowly cooled from about 1200° F., are embrittled when quenched from about 850° F. Irons similarly treated but slow cooled from 850° F. have their ductility progressively increased during the slow cooling cycle. In fact, after short periods at 850°, the ductility of the iron might be fully restored. Phosphorus and silicon increase the susceptibility to temper embrittlement while the addition of molybdenum inhibits the action.

"Inoculation of Gray Cast Irons" by N. C. McClure of Dow Chemical Co., Midland, Mich., and his associates described the effect of various addition agents on the relatively low-carbon high-strength irons – materials selected because of their tendency toward unfavorable graphite distribution and their sensitivity to inoculation additions. Silicon, silicomanganese, ferrosilicon and silicon-manganese-zirconium additions, which were free of calcium and aluminum, were not effective inoculating agents. On the other hand, a calcium-silicon alloy containing approximately 30% calcium was the most effective one – in fact, better than calcium alone. Calcium also reduced chilling tendency, cell size of the microstructure, and the carbon content of molten iron. Aluminum was a powerful chill reducer, but its addition did not promote Type A graphite distribution.

Summary

These few citations from the 94 formal papers and 14 round tables or discussion groups, as well as the exhibits of the 100 firms at the "First Engineered Castings Show" emphasized that the American foundry industry is alive to the day-to-day changes in our rapidly expanding economy. Frequently, production technology is considerably ahead of customers' demands. Especially is this true in circumstances where practice is frozen by long-established specifications. From corridor conversation at the light metals session and at the sessions on steel castings one gets the impression that the big problem now is to get the customer to realize the possibilities of castings made by 1957 methods and to put them to work – work at their present capabilities, not at the levels considered acceptable in past decades.



Reproduction of Wood Cut From Swedenborg's Text "Ars Emolliendi et Ferro Purificandi (1734) Showing an Embryonic Converter

An 18th Century Precursor of Kelly and Bessemer

*By MYRON WEISS**

IN 1857 WILLIAM KELLY of Kentucky finally applied for a U.S. patent on the converter for decarburizing cast iron which he had developed some time before, but the previous year Henry Bessemer had taken a patent out in England on a practically identical device. Astute, aggressive promotion has fixed the name *bessemer* on the Kelly-Bessemer converter and process, the springboard for the tremendous 20th century steel culture.

Yet more than a century before Kelly and Bessemer, in 1722 in fact, René-Antoine Ferchault de Réaumur in France (whose name survives in a thermometric scale) and in 1734 the philosopher Emanuel Swedenborg in Sweden had described a method of converting cast iron into steel and pictured the converter and its parts. Réaumur's French "L'Art de Convertir le Fer Forgé en Acier" was translated into English by Annaliese Grünhaldt (Mrs. Frank) Sisco last year with support of the American Iron and Steel Institute, as "Memoirs on Steel and Iron". It has most to do with the cementation process of changing wrought iron bars into high-carbon steel for tools and implements.

The only translation of Swedenborg's Latin text, "Ars Emolliendi et Ferro Purificandi," into any language is a Swedish one of the 1920's. A minor reason for this neglect is that Swedenborg's Latin is a translation, yet an interpretive one, of Réaumur's earlier report. Honest, careful, generous Swedenborg, in acknowledging the priority, termed Réaumur "Clarissimo Domino", although he was by far the most illustrious master.†

The major reason for this neglect is that Emanuel Swedenborg (1688-1772) is now known almost solely as a mystic and theologian. Yet for 32 years, between 1716 and 1747, he was assayer of the Swedish Board of Mines.

The Réaumur-Swedenborg converter illustrated is a portable, tilting combination of blast furnace, crucible and openhearth! The stack is of clay reinforced with internal iron rods and further strengthened with outside hoops. The bottom is a removable pot lined with reinforced clay. The reinforcement here is a slatted bucket, a similar construction to trays used now in heat treating furnaces. At the bottom of the stack, immediately above the crucible, is the tuyere into which the nozzle of the bellows fits. Directly opposite is the taphole, to be plugged with clay. The charge of broken pieces of cast iron and charcoal was fed into the stack, held in the vertical position, from above. The bellows blast was directed downward on a slant against the opposite side of the crucible. In this ingenious manner the blast melted the charge, stirred the melt and decarburized the iron all at one time. When the iron was properly purified, a mold was trundled up to the converter, the tap pulled, the converter tilted on its trunnions, and the steel poured.

In addition to his treatise on iron and steel, Swedenborg also wrote on copper and brass ("De Cupro et Orichalco"). This was not translated into English until 1901 (by Arthur Hodson Searle in England) and not published until 1938 when the British Nonferrous Metals Research Association photo-reproduced Searle's typewritten manuscript. Neither carry Swedenborg's beautifully expository illustrations. This "Copper and Brass" ought to be republished by letterpress. Indeed, all of Swedenborg's metallurgical, mining and engineering works ought to be put into English very soon. American research, engineering and development surely have risen to such levels of prosperity and self-confidence that they can carry this trifling cost of professional culture.

*Editorial Counsel, New York.

†Swedenborg's work is the more comprehensive. It contains, for example, notes on the "smelting of iron ore and refining crude iron in Maryland and Pennsylvania".

Mechanical Properties of C 355 Aluminum Casting Alloy

*By T. H. OWEN and L. E. MARSH**

This high-purity, low-iron alloy, adequately degassed, will have elongation 100% better than standard 355 alloy at equal ultimate and yield or, when elongation is equal the ultimate and yield of C 355-T 62 are 25 to 30% higher than 355-T 6.
(Q27a, E25s, J27a, 1-10; Al)

Whenever a new engineering material such as high-purity 355 aluminum alloy becomes generally available, many questions are asked as to what may be expected of it in general casting applications involving high stress.

Casting alloy 355 (nominally 5% Si, 1.3% Cu, 0.5% Mg) has for many years been known to have excellent foundry characteristics and be capable of heat treatment to high ultimate and yield strengths, but is lacking in ductility when its maximum strength is developed. Control of impurities, particularly of iron to a point of 0.2% or less (alloy C 355), improves this versatile and widely used material. How much does it improve the properties, and under what conditions?

Obtaining answers to these two questions requires careful and somewhat complex testing, but fortunately the evaluation does not have to be as complex as the conditions under which a casting may be made. Many of the variables encountered in the foundry (mold materials, mold design, size, shape and section thicknesses in the casting) are primarily important in their relationship to mechanical properties as they affect, basically, the rate and progression of solidification. Consequently, if mechanical properties are measured in relation to a wide range of solidification rates, an over-all picture is obtained of what the alloy will do under many of the various conditions which are imposed upon it by casting forms and dimensions, and by the molding technologies employed.

This evaluation we have attempted to make for Alloys 355 and C 355. In addition to solidification rates, we have appraised the effects of certain variations in heat treatment, and vacuum versus nitrogen degassing (hydrogen removal). As shown in Table I, work was done on three heats of alloy C 355 (low iron) and two heats of the standard alloy, 355, which usually contains between 0.25 and 0.40% iron as supplied in

*Mr. Owen is a development engineer, and Mr. Marsh is manager of casting development, both of Morris Bean & Co., Yellow Springs, Ohio.

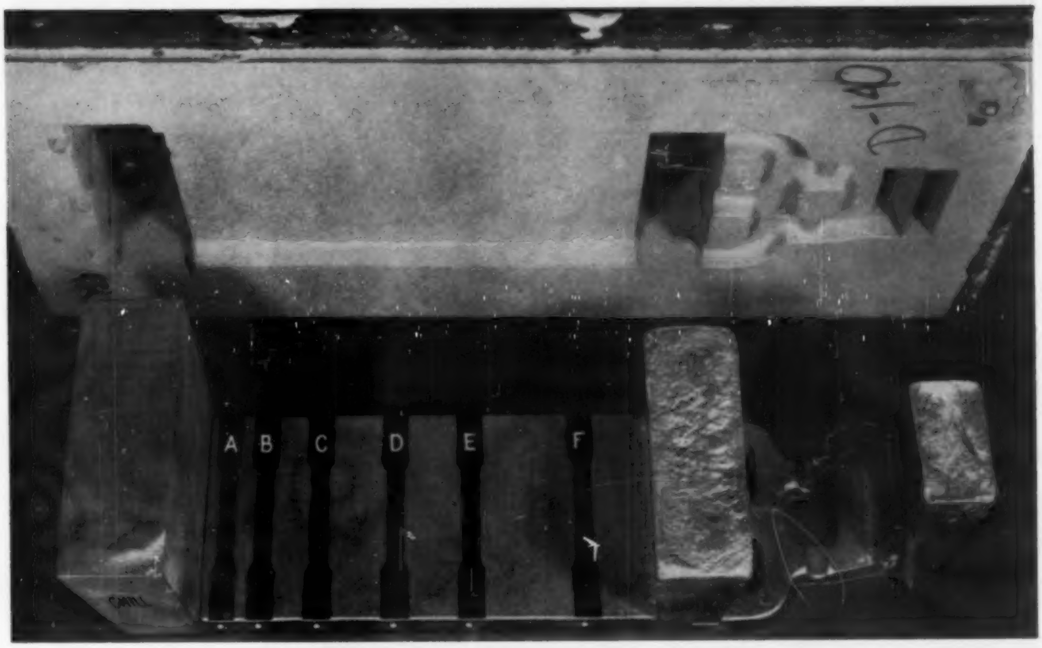


Fig. 1 – Test Slab and Cope Mold With Chill in Position at Left. Inked bars show locations where standard tensile specimens were machined.

primary ingot. Ingots came from two suppliers. The heats were selected as being representative of each alloy as currently supplied to industrial fabricators.

The test casting made for this evaluation is shown in Fig. 1, with a typical cope mold made of gypsum-bonded sand. The casting is a flat slab ¾ in. thick, poured and fed from one end, and chilled with a large aluminum chill across the opposite end. The contact area of the chill is limited to the vertical dimension of the slab. The riser is somewhat larger than would be required for feeding. Width of 6 in. was chosen so that the standard 0.505 by 2-in. tensile test piece could be prepared. Thickness of ¾ in. is representative of many of the heavier aluminum castings required for applications involving high stress. The 12-in. length provides the range in solidification rates desired for the study.

Solidification times were obtained from cooling curves drawn by thermocouples placed at positions corresponding to the center of the axis of each test piece as shown in Fig. 1. Time between pouring and freezing at these various stations is as follows:

Test Bar	Distance From Chill	Time to Freeze
A	0.5 in.	40 sec.
B	1.5	1 min. 40 sec.
C	3	3.5 min.
D	5	7
E	7	10
F	10	15

It was noted that the solidification time is proportional to the distance from the chill for the section of the casting between 3 and 10 in. from the chill.

Separately cast test bars from the standard three-bar pattern were also poured in baked sand molds, bonded with cereal and oil. In all, 15 heats were melted, 70 slabs like Fig. 1 were cast and tested in the

Table I – Alloy Composition (From Suppliers' Certification)

Fe	Cu	Si	Mg	Zn	Ti	Others
			Alloy C355			
0.14	1.24	5.08	0.52	0.01	0.12	0.001 Ca; 0.005 B added
0.12	1.16	5.10	0.54	0.01	0.13	0.001 Ca; 0.005 B added
0.11	1.32	5.00	0.54	0.02	0.12	0.02 Mn; 0.01 Ni
			Alloy 355			
0.39	1.36	5.19	0.48	0.03	0.13	0.01 Mn; 0.002 Ca; 0.005 B added
0.31	1.24	5.09	0.52	0.02	0.13	0.01 Mn

Fig. 2 — Vacuum Degassing Apparatus in Open Position

locations indicated, and 201 test bars cast separately.

Procedure for a typical heat for this study was as follows: 240 lb. of ingot was run down in a 400-lb. gas-fired tilting furnance, and its temperature raised to 1400° F. Then 20 lb. of metal was ladled into a hot 30-lb. crucible (Fig. 2) and the crucible covered, evacuated and held a minimum of 15 min. The vacuum attained was between 400 and 1000 microns. After degassing, a set of test-specimen castings was poured at 1310° F. This procedure was repeated three times to obtain all the castings required.

In the meantime, the metal remaining in the furnace was being degassed with nitrogen. The flow of nitrogen was continued until a sample made with a conventional reduced pressure test showed no evidence of gas. The fluxing time required was generally 30 to 45 min. Test specimens were then poured, at 1310° F., from the nitrogen-fluxed metal.

All of the slab castings were radiographed, and were consistently excellent in appearance throughout.

All slabs and bars were solution treated at 980° F. for 14 hr. and quenched in boiling water (except one heat which was quenched in water at 140° F.). Castings from four of the heats were given the T 62 heat treatment (aging 14 hr. at 340° F.); two of them the T 61 heat treatment (aging 8 hr. at 310° F.); two the T 6 heat treatment (aging at 310° F. for 3 and 5 hr. respectively, the limits permitted in the specification).

After the heat treatment, 0.505-in. diameter bars were machined from the slab castings as shown in Fig. 1. (The "E" bar, 7 in. from the chill, was omitted because previous experience with this alloy had shown that little difference in properties appeared between 5 and 10 in. from the chill.) Ultimate, yield, and elongation values were obtained for all machined and separately cast bars. Brinnell readings were taken on approximately one-third of the bars, prior work having shown constant hardness readings throughout this test casting after a particular heat treatment.

Effects of Degassing Practice — The average mechanical properties obtained from the nine heats of C 355 alloy (three of each analysis shown in Table I) are shown in Fig. 3. The curves show the properties of slabs in the T 62 condition. The solid black lines represent the nitrogen-fluxed metal and the broken white lines the vacuum degassed metal. Separately cast bar results are also shown in short lines at the left.

A comparison of the properties of metal degassed by the two methods indicates that if dissolved hydrogen is removed either way to

the same level (as shown by radiographic porosity ratings) the mechanical properties will be substantially the same. Vacuum degassing may give results that are a little more consistent.

Shaded areas show the extent of variation obtained in test bar values as measured by the standard deviation of values for each distance from the chill. Since the two curves are so close and the data show the same extent of scatter, results for each point were combined in figuring the standard deviations. The average standard deviation for ultimate strength is ±1034 psi.; for yield strength is ±942 psi.; and for elongation is ±0.45%. Considering that there were chemical differences in the materials evaluated, and that nine different foundry heats were run, this high degree of consistency shows that close control was exercised during the test procedure.

Figure 4 compares the C 355 alloy (low iron) and the standard 355 alloy in the T 62 condition. Figure 5 is included to show the variation of properties obtainable with the standard alloy within the T 6 specification, and Fig. 6 compares the two after they have been heat treated to obtain equal elongation. Figure 7 compares the mechanical properties obtained from C 355 slabs in the T 62 condition after quenching from the solution treatment in boiling water (as is usual) or in water at 140° F.

High Strength – In the evaluation of the advantages to be derived from using C 355 alloy for highly stressed aluminum castings, the most significant comparison is in Fig. 6. Here the elongation curves have been duplicated very closely for the two materials, C 355 and 355. The gain in strength achieved by C 355 alloy in the T 62 condition averages about 8000 psi. for both the ultimate and yield values – a gain which is fairly consistent for all parts of the slab casting, though it tends to be a little greater in the slowly freezing areas. This increase is approximately 25% in ultimate strength and 30% in yield strength. Comparison of the two when both alloys are in the T 62 condition (Fig. 4) does not show much difference in strength, but the elongation in the standard alloy is only about half that of the high-purity metal in all parts of the casting.

Control – Not only are the combined mechanical properties of C 355-T 62 superior to the standard alloy to the extent shown by the curves in Fig. 6, but they are under better control. The properties can be held to closer limits, both because of the consistency of the suppliers' product, and because of the reproducibility of the temper.

Fig. 3 – Mechanical Properties of C 355 (Low-Iron) Castings, ¾ In. Thick, After Nitrogen or Vacuum Degassing, and Heat Treating to T 62 Condition. Shaded area represents one standard deviation on either side of average value, as calculated from the values for both nitrogen and vacuum degassing

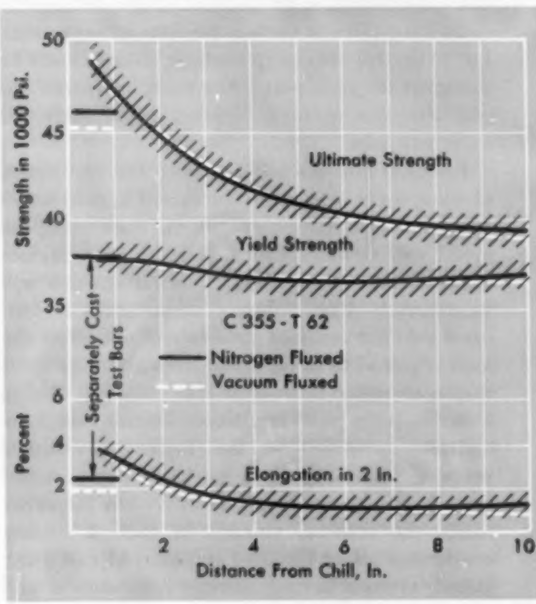
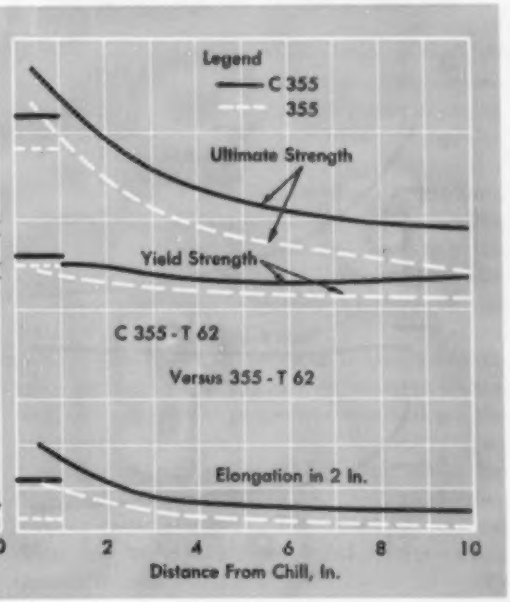


Fig. 4 – Mechanical Properties of High-Purity C 355 and Standard 355 Alloy. Test castings ¾ in. thick heat treated to the T 62 condition

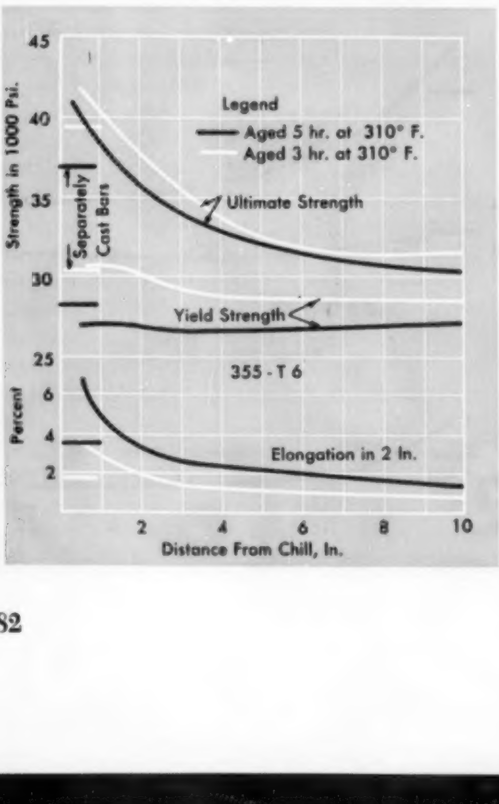


As shown by Fig. 5, a large variation in properties of 355 is obtained within the T 6 specification (often used with the standard alloy to obtain the ductility required) because of the relatively rapid rate at which the properties are changing when the aging treatment is terminated; variations in the chemical composition of the standard alloy tend to increase this range of properties. Another advantage of C 355-T 62 is that the aging procedure puts the alloy in a relatively stable condition which does not change in many high-temperature applications.

The well-known effect of solidification rate on the mechanical properties of the metal is shown quantitatively by the graphs. Figure 3 for C 355-T 62 shows that the ultimate strength is approximately 25% higher at the chilled than at the fed end of the casting – 49,000 as compared to 39,000 psi. The elongation is about 4% at the chilled end as compared to 1% at the fed end. Yield strength is relatively unaffected by solidification rate. Examination of slab fractures and of radiographs indicates that the entire test casting is well fed. However, there is some microporosity starting between 2 and 3 in. from the chill and increasing slightly toward the riser end. These discontinuities are not of a size that can be shown as defects by conventional radiography.

The fracture at the chill end of the casting is extremely fine grained and homogeneous. The grain size increases toward the riser, and the fracture becomes more coarse, with larger flat crystal faces evident. If this slab fracture is used as a standard and correlated to the data in the curves, fracture appearance can be used to predict within a close range the mechanical properties of other castings in the same temper condition. This provides a simple control which can be used to advantage in the foundry in the development of castings for high-strength applications.

Fig. 5 – Mechanical Properties of ¾-In. Slab Castings of 355 Alloy Aged to the High and Low Limits of the T 6 Specification



Separately cast test bars correspond to only a single point on the property curves for the test slabs, namely a section between 1 and 2 in. from the chill in ultimate strength, and to a section between 1½ and 2½ in. from the chill in elongation for all curves except 355-T 62. For the latter they correspond to a section between 3 and 4 in. from the chill. Separately cast bars correspond fairly closely in yield strength to the values obtained throughout the test slab.

Fast Quench – Figure 7, the curve showing the effect of the quenching rate on the mechanical properties of C 355-T 62, is included because some specifications for highly stressed castings require a cold water quench; higher mechanical properties are obtained in this manner. Castings of this alloy group are normally quenched in boiling water to reduce the residual stresses induced by differential cooling rates within the casting during such quenching, caused either by vapor pockets in the quenching medium surrounding the casting or by the variation in section thickness of the casting itself. The residual stresses can be controlled or minimized by differential quenching rates at various sections and openings, but to do this special quenching fixtures must be designed for each part. For complex pieces this may become quite expensive, particularly for short run jobs.

Residual Stresses – It has been the experience of some users of castings quenched in cold water that if there is enough ductility in the casting the metal will yield slightly under the load stresses imposed and the residual internal stresses will be relieved. Under these circumstances it is argued that the residual stresses will not affect the load required to bring about ultimate failure. If this contention is true, if the principal design criterion is the point of ultimate failure, and if the ductility is sufficient, the higher mechanical properties of a rapidly quenched casting should increase its load-carrying ability. On the other hand, the residual stresses in such a casting would still affect the load required to cause the initial, stress-relieving, plastic deformation and

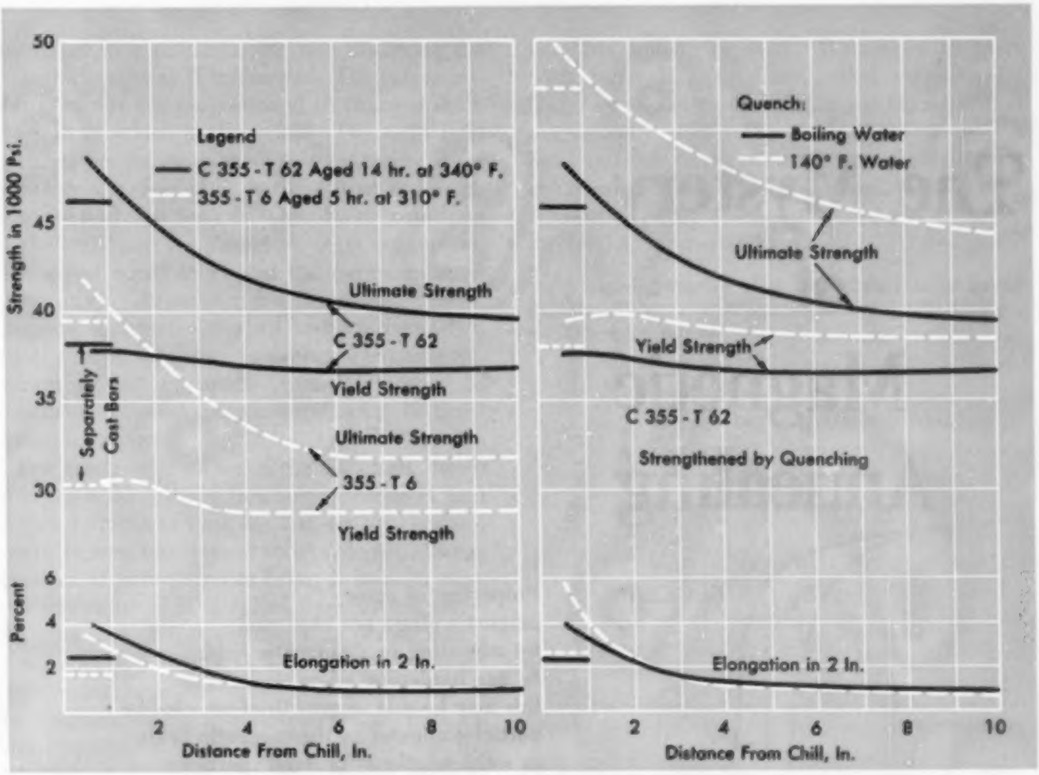


Fig. 6 – Mechanical Properties of ¾-In. Slab Castings of C 355-T 62 Compared to Those of Equivalent 355 Test Castings Heat Treated to Equal Elongation

Fig. 7 – Comparison of Properties of C 355-T 62 Test Castings Quenched in Boiling Water and in Water at 140° F.

could, in items of insufficient ductility, affect the load at ultimate failure. The residual stresses could also have a pronounced effect on the performance of castings subject to fatigue loading, since the stresses imposed in them do not ordinarily exceed the yield point. Residual stresses also affect the dimensional stability of the casting during machining.

The elongation curve in Fig. 7 obtained with the 140° F. water quench shows a considerably increased elongation in the metal affected by the chill and a slightly lower elongation in the remainder of the casting. This variation in responsiveness to the quenching rate has been observed previously. In castings which are highly chilled and well fed, an increase in the quenching rate has been found to increase the elongation and ultimate strength, and to lower the yield strength slightly. In castings which have a slower solidification rate and correspondingly coarser grain structure, the effect of an increased quenching rate has been to increase the ultimate strength and the yield strength and to decrease the elongation.

Summary – A comparison of the properties of standard and high-purity 355 alloys in the T 62 condition indicates that the elongation is improved up to 100% with the high-purity material, and that ultimate and yield strengths are improved slightly.

If the standard 355 alloy in the T 6 condition will meet the minimum ductility requirements, equal ductility can be obtained by using the high-purity C 355 alloy in the T 62 condition with an increase of 25% in the ultimate strength and 30% in the yield strength.

If the gas content of the metal is lowered to the same point by either vacuum or nitrogen degassing, the mechanical properties obtained will be the same.

Mechanical properties of 355 type alloys are improved by quenching in 140° F. water rather than in boiling water. The effect of residual stress has to be evaluated fully before such a quench is used.

The Mystery of Magnetic Annealing

*By J. J. BECKER**

Properties of some magnetic alloys are improved by annealing in a magnetic field. In age hardening alloys this may be due to growth of needle-like particles aligned by the magnetic field; in solid solutions "ordered" particles may grow in similar shapes, or atom-pairs may be aligned with the field. (P16, J23; SGA-n)

A WELL-KNOWN FIGURE in the business of making magnetic materials was recently asked what was going to be made in a new plant his company was about to open. He placed an arm around the shoulder of his youthful inquirer and beamed, "Son, we're going to make money." Some of this desirable product will come, as it has for years, from the sale of metal that has been heat treated in a magnetic field.

Magnetic annealing is practiced commercially on a variety of alloys and sometimes alters their magnetic properties to an extreme degree, even though the exact origin of these changes remains a fascinating puzzle. In this respect, it is like many another metallurgical process. It was discovered by accident, and has grown very useful, but we are not sure just why it works. If we knew more about it, we might be able to do it still better.

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A Few Terms – You may have seen rather mysterious looking plots like Fig. 1, which supposedly tell the initiated all about the magnetic properties of some material. Perhaps a few words of explanation will do no harm.

The ordinate H, plotted horizontally in Fig. 1, is the magnetic field strength applied to the material. (65 Permalloy is plotted at left of Fig. 2, and Alnico 5 at right.) The magnetic field is usually created by passing an electric current through a coil of wire surrounding the specimen; the field strength H is proportional to the current and to the number of turns per unit length in the coil – in fact, the unit of magnetic field strength can be determined in these terms. The unit of H is the oersted and it corresponds to a definite number of ampere-turns per unit length.

The vertical ordinate B in Fig. 1 is the magnetic flux density in the material produced by a given H. Magnetic flux density is measured by winding another coil around the specimen, con-

necting it to a galvanometer, and observing the voltage changes as H is changed. The galvanometer readings are proportioned to changes in B, the unit of which is the gauss. The ratio B/H is called the permeability. If we measure B for a variety of values of H, both positive and negative, we find that for air (when there is nothing in the coil) and for almost all other substances, B is about equal to H and the permeability is about unity. However, a few things called ferromagnetic materials differ markedly in two ways. First, the permeability is high; in extreme instances it may go up to the neighborhood of a million. Second, the material tends to resist *de*magnetization.

For example, if either of the materials shown in Fig. 2 is magnetized in a large positive H, and H then reduced to zero, the flux density does not return to zero but stays at some value B_r. Some negative H is required to bring B back to zero, and this value of H is called the coercive force, H_c. Because of this resistance to demagnetization, a plot of B against H, as H is cycled through positive and negative values, encloses an area on the diagram called a hysteresis loop (Fig. 1). The magnitudes of B_r and H_c depend on the structure of the material. In fact, the coercive force H_c is one of the most structure-sensitive properties known, ranging from thousands of oersteds in a permanent magnet to thousandths of an oersted in alloys bred to magnetize easily.

In the development or improvement of magnetic materials one is usually trying to push H_c to either infinity or zero. Permanent magnets with large H_c are often called magnetically "hard", while materials with small H_c are called magnetically "soft". Obviously these two words hard and soft refer only to how easily the material is magnetized or demagnetized, and have no connection with indentation hardness or other mechanical properties*.

*A useful discussion of these matters is to be found in "Metallurgy and Magnetism", by J. K. Stanley, published by A.S.M.

Fig. 1 — Hysteresis Loop of Ferromagnetic Material

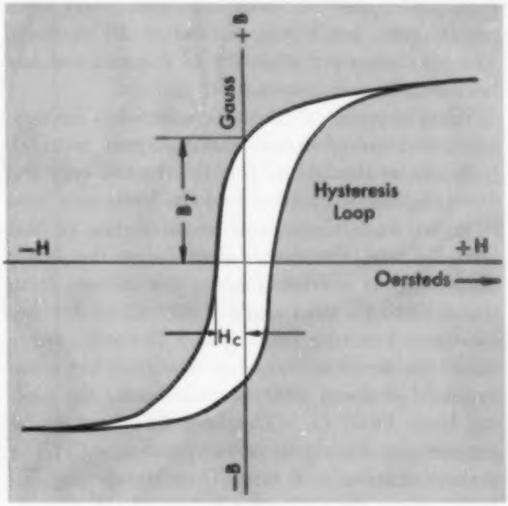
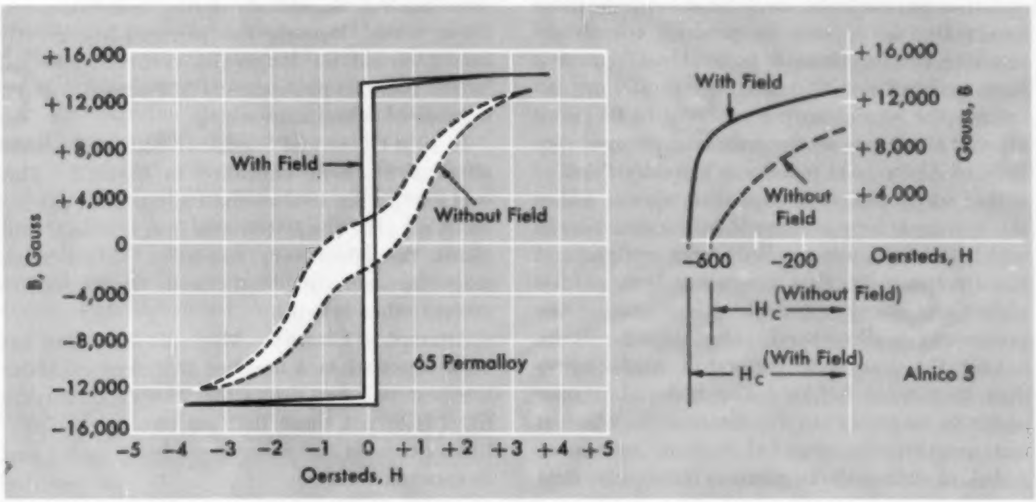


Fig. 2 — Effect of Magnetic Field During Slow Cooling on Magnetic Properties of 65 Permalloy (a Soft Magnetic Material) and of Alnico 5 (a Hard Magnetic Material)



Soft Softer, Hard Harder – Figure 2 shows the effect of annealing two typical materials in a magnetic field. Here we immediately come face to face with the remarkable fact that "magnetic annealing", so-called, is practiced for two reasons – *(a)* to make soft magnetic materials softer and *(b)* to make hard magnetic materials harder. For example, 65 Permalloy is a magnetically soft alloy containing 65% nickel and 35% iron, whose very high permeability (B/H ratio) makes it useful for sensitive relays and delicate electrical equipment. If it is slowly cooled from above the magnetic Curie temperature (about 600° C.) its hysteresis loop looks like the one shown dotted in the left-hand diagram of Fig. 2. The narrow Z-shaped hysteresis loop drawn in solid lines results from cooling in a field of 10 oersteds. The maximum permeability of the material has been enormously increased.

What happens to Alnico 5, which has become an almost universal permanent magnet material, is shown at the left of Fig. 2, wherein only the demagnetization quadrant of the hysteresis loop is given, as is customary for materials of this kind. Again, the dotted line shows the result of cooling at several degrees per minute from about 1300° C., then aging at 600° C. to develop maximum coercive force (H_c). The solid curve shows the result of the same treatment but within a field of about 1000 oersteds during the cooling from 1300° C. (The field turns out to be unnecessary during the subsequent aging.) The maximum value of B times H on the demagnetization curve (the "energy product" that measures the excellence of a permanent magnet material) has been more than doubled by such magnetic heat treatment.

Although magnetic heat treatment of these two materials appears to produce completely opposite results, there is no real conflict. We have pointed out that magnetic annealing increases the maximum permeability of 65 Permalloy; it also increases the maximum permeability B/H of Alnico; one just doesn't usually think of it that way. Magnetic annealing always makes the hysteresis loop, measured in the direction in which the field was applied, more upright and more rectangular, thus increasing both permeability and energy product. The resulting improvement is directional. One pays for it by having the transverse properties made worse than they were before. The material is now easier to magnetize in the direction in which it was magnetically annealed than in any other. A disk of such material place in a magnetic field will try to rotate so that this preferred direction lies along the field. The torque it exerts in trying to do so can be measured and used as an indication of the strength of the magnetic annealing effect. Since magnetic annealing produces a new magnetic "easy direction" in either soft or hard materials, one is led to suspect that similar changes are taking place in both.

Ancient History – What, then, are the metallurgical changes responsible for the changes in magnetic properties brought about by magnetic annealing? An obvious place to start is to list all of the materials in which an effect has been found and see if they appear to have anything in common.

The earliest reference to the effect seems to be by Pender and Jones in *Physical Review* for 1913. They discovered noticeable changes in the hysteresis loops of specimens of 3.5 and 4% silicon steel – or, as they put it, "such silicon steels as are currently used in electrical manufacture". Magnetic annealing of silicon steel has been rediscovered about every ten years ever since, and the fact that it was the very first material to exhibit the effect may still come as a surprise to some people.

Next comes a fairly comprehensive paper by Kelsall in 1934. He had apparently accidentally discovered magnetic annealing in 78% nickel Permalloy some ten years before. He explored quite a variety of systems, including Perminvar, an alloy of about 45% nickel, 25% cobalt and 30% iron having low but constant permeability for a range of applied field – a useful property for some applications. It was already known (and patented) that the way to make good Perminvar was to be careful to *avoid* any magnetic fields in the vicinity during heat treatment; these would increase the permeability greatly but it would no longer be constant. Kelsall looked into this phenomenon in Perminvar and a number of other materials.

In 1938 Oliver and Shedden discovered a small effect of magnetic annealing in Alnico 2. This was followed in 1940 by the Phillips Co.'s patents on Alnico 5, which contains more cobalt and shows the effect very markedly. Since then, magnetic annealing has been discovered in several other systems.

Attempt to Classify – Magnetic annealing has been reported in a number of systems. About the best one can do in the way of classifying them is to put those that are clearly precipitation systems in one column and lump all the rest in another, thus:

Precipitation Systems	Others
Alnico 2	75 Ni, 25 Fe (Permalloy)
Alnico 5	Ni-Fe-Co (Perminvar)
Cobalt ferrite	50 Fe, 50 Co
Cu-Co	Ni-Co
	Fe-Si (silicon iron)

Alnico 2 and Alnico 5 are certainly precipitation alloys,* although a good part of what goes on in them has yet to be straightened out. Co-

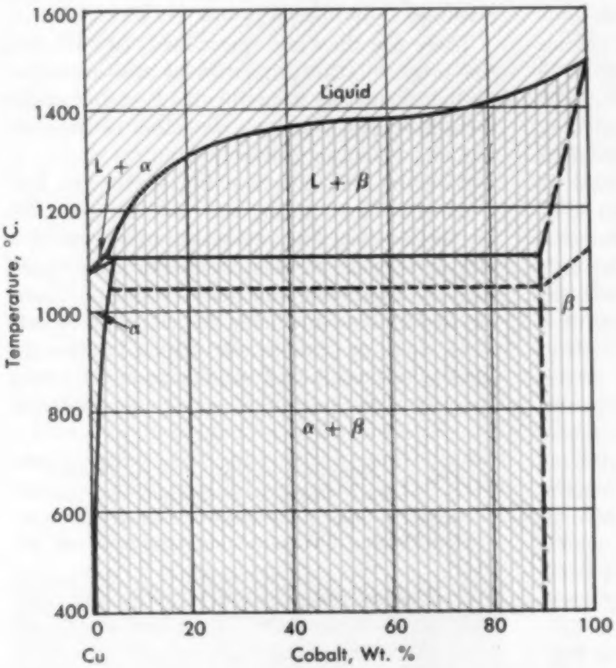


Fig. 3 – Equilibrium Diagram of the Copper-Cobalt System

balt ferrite refers to a mixed oxide of cobalt and iron, having permanent-magnet properties which it owes to a precipitation reaction. Magnetic annealing has recently been discovered by Miyahara and Mitui in alloys of copper containing a small amount of precipitated cobalt.

In the second column we find the Permalloys, centering around 75% nickel and 25% iron, and the Perminvars. Iron-cobalt alloys also show the effect of magnetic annealing, especially around the 50-50 composition. It also has recently been discovered over a wide composition range in the nickel-cobalt system. Finally, there are the iron-silicon alloys, in which the effect was first found.

Ordering – Taking a second look at the right-hand column, one begins to suspect that "ordering" may have something to do with all this. "Ordering" is the opposite of "disorder", wherein the two kinds of atoms in a binary solid solution are sprinkled randomly on its crystal lattice points. Each atom might, however, prefer to have the opposite kind next to it. The more this happens, the more often opposite kinds of atoms appear as neighbors, the more highly "ordered" the alloy. If there are equal numbers of atoms, or three of one kind to one of another, and the crystal lattice is of the right kind, ordering can become 100% complete. In many ordered structures, each atom can be entirely surrounded by atoms of the other kind. (This is sometimes called the "John loves Mary" theory.)

When there are three atoms of nickel to one of iron (Ni_3Fe in the Ni-Fe system) we have a well-known ordering system, as is also the equal-atom composition in the Fe-Co system. Ordering is also believed to be responsible for the property changes in Perminvar.

On the other hand, ordering has not yet been found in the nickel-cobalt system. While this, of course, does not mean that it does not order, the wide composition range over which magnetic annealing occurs in this system leaves one a little uneasy with the ordering hypothesis. The same is true of the iron-silicon system. The fact that there is an ordering reaction at 12% Si by weight (one silicon atom to three irons) may not be too helpful in explaining magnetic annealing at 3% silicon.

The Mystery of Alnico – Let us go back again to the precipitation system. Much as we might like to, we can hardly start with Alnico and get to the bottom of magnetic annealing. The trouble is that no one really understands yet what Alnico is! It is one of those materials that Nature, in her generosity, has permitted us to stumble across. It contains very nicely adjusted quantities of iron, nickel, aluminum, cobalt, copper, and sometimes titanium; it is subjected to an improbable heat treatment, and comes out with the best permanent magnet properties

*In the sense that heating to a high temperature will put certain metals or compounds into a solid solution which is metastable at lower temperatures and these phases will be precipitated as a dispersion of particles during a stay (or aging) at a lower temperature.

known. Many people busily manufacture it; a few souls meanwhile grope about in the darkness trying to figure out why it is endowed with such remarkable properties. The compositions of the phases involved are unknown; there is no agreement on their crystal structures, or their Curie temperatures, or their magnetic saturations. In fact, not even the number of phases involved is settled. Clearly this is not the ideal system for a study of the modifications brought about by heat treating in a magnetic field.

Copper-Cobalt – Now let us take a closer look at a simple system – copper-cobalt. The phase diagram, Fig. 3, shows that it should be age hardenable in the usual way. Thus, an alloy containing about 2% cobalt can be solution treated at around 1000° C. and quenched at room temperature as a nonmagnetic solid solution. If it is then reheated to a lower temperature, such as perhaps 700° C., the cobalt-rich beta phase can be precipitated. The material then consists of a finely divided precipitate of a ferromagnetic phase in a nonmagnetic matrix.

Miyahara and Mitui discovered that if the cobalt-rich phase is precipitated in a magnetic field, the material will have directional magnetic properties. I have been interested in this system, which looks as though it might have a certain similarity to Alnico, but perhaps be several orders of magnitude simpler. It turns out to have a few tricks of its own; however, I have been able to find out one very interesting thing about the course of magnetic annealing in this particular material. The upper curves in Fig. 4 show the magnetic saturation, which is a direct measure of the amount of precipitated phase present, while the lower curves show the effect of magnetic annealing, measured by the maximum torque on a disk of the material in a field. Both of these are plotted against aging time at 650 and 700° C. respectively.

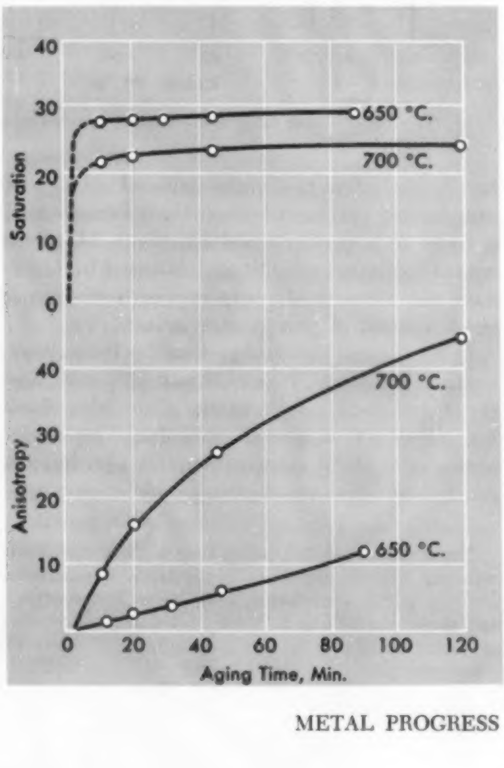
It is very clear by the upper curves that precipitation is complete in less than 10 min., the shortest aging time studied. It is likewise complete before any appreciable magnetic annealing effect begins to show up in the lower curves. Throughout these experiments, the total amount of precipitated cobalt is constant after 10 min. and the average particle size is increasing as time goes on. Whatever the field does, it does during the growth of the particles. It does *not* affect the nucleation of the precipitate, although this is a natural idea that has turned up often in the literature discussing magnetic annealing.

Precipitation Alloys – The evidence supports the idea that properties of a magnetically annealed specimen must be related to the properties of the individual precipitated particles. In any event, these have their own magnetic "easy" directions. If they were not formed while the alloy is in a field, their easy axes point in random directions. What the field does is in some way to line up the easy directions of the particles, thereby producing an effect in the specimen as a whole.

There are then two questions: (*a*) What is the origin of the properties of the individual particles? and (*b*) what does the field do to make them line up? There are a number of possibilities, and I shall suggest only one.

With the clue shown in Fig. 4 that the field is effective only during the very early growth of the particles, it is reasonable to say that the properties of the particles are due to an elongated shape. A growing magnetic particle, if magnetized in one direction, should tend to add atoms so as to grow needle-shaped. When the particle is cooled and growth stops, the long direction is its direction of easiest magnetization,

Fig. 4 – Saturation and Antisotropy (Plotted in Arbitrary Units) in a Magnetically Annealed Copper Alloy With 2% Cobalt, Solution Treated, Quenched, and Aged as Shown



simply because of this shape. If all the little particles have their long axes parallel, the entire specimen will show the torque and the differing hysteresis loops in different directions characteristically produced by magnetic annealing.

An electron micrograph might be able to prove this hypothesis, but work in these extremely small size ranges is difficult. It does appear that the particles in Alnico are elongated, and that they point their long dimensions in the direction in which the field was applied during magnetic heat treatment.

These ideas could be extended to the alloys which order. The ordering process can take place either uniformly and gradually throughout the whole material, or by the formation of particles of ordered phase in a matrix of still disordered material. Some systems seem to order one way, some the other, and quite a few are still being argued about. Now, if ordering goes by particle formation, it is just like an ordinary precipitation process and the shape idea carries over directly; the particles of ordered phase would be elongated, and field annealing would line them up.

However, it is hard to understand the very high permeability in magnetically soft materials of the ordering type if they are really two-phase structures as postulated above, because the usual way to go after high permeability is to try for a homogeneous single-phase structure, and to remove every sort of imperfection, impurity, cold work, or second phase. Permanent-magnet materials, on the contrary, are characteristically multiphase alloys. Of course the ordered-phase hypothesis is not going to work in systems that turn out not to order.

Pairs — There may be a more general sort of process going on in solid solution alloys. The idea was first proposed by Néel, an eminent French worker in magnetism.

Think now of a simple solid solution, Forget all about ordering. Say it contains some iron atoms and some other atoms, such as silicon, which we may regard as nonmagnetic holes. Here and there these holes will occur in pairs. Such a pair will have a lower energy if it is parallel to the magnetization in its vicinity than if it is crosswise. A nonmagnetic void prefers to be aligned with a field, just as a magnetic particle does. If the temperature is high enough for diffusion, such atom pairs will tend to align themselves with the magnetization. If the material is all magnetized in one direction by an applied field, atom pairs will tend to point in one preferred direction throughout the material. If this structure is then frozen in by cooling, magnetization will now be easier parallel to the axes of the pairs than crosswise to them. The material will then be magnetically annealed.

What happens in a system such as iron-nickel, containing only magnetic atoms, cannot be described in quite such a simple way, but the principle is the same. Like-atom pairs prefer to point in the direction of the local magnetization, and will do so if diffusion permits.

What Next? — We are left, then, with two kinds of systems, precipitation alloys and solid solutions. There appear to be several experiments that ought to be tried right away. If ordering has anything to do with magnetic annealing, the one system that should do it better than any other is Ni_3Mn because, over a wide range of temperature, ordered nickel-manganese has a very high saturation. On the other hand, the disordered material is nonmagnetic. If the like-atom-pair picture is right, there must be many solid solutions which will prove to be susceptible to magnetic annealing, provided diffusion can take place at a temperature well below the magnetic Curie point.

One very recent discovery should be mentioned at this point, which has to do with films of magnetic materials formed by deposition from the vapor. It has been found that films of iron, nickel, cobalt, and some of their alloys are magnetically annealed if they are deposited in the presence of a magnetic field. The field determines the easy direction of the deposited film. This behavior does not fit in with any of the above discussion, since it occurs in pure metals, where there is only one kind of atom and thus nothing to order or form pairs. One now has to think either about stresses or the alignment by the field of some structural defect in the film. Nature, as always, is one jump ahead of us.

Doubtless everyone feels that his own particular field of interest has an exceptionally large number of fascinating problems in it. The relationship between metallurgical structures and magnetic behavior certainly appears to have at least its share of unexplored mysteries. The unraveling of the problem of magnetic annealing strikes me as especially appealing to the physical metallurgist. The concepts involved are not particularly abstruse, and the experiments are delightfully simple, as experiments go. The problem has much scientific significance. As if this weren't reason enough, the results might be extremely useful. Who knows?

Book Review...

A Practical Reference Book on Carbon Steel

*Reviewed by ELMER H. SNYDER**

STEELS FOR THE USER, by R. T. Rolfe, 3rd Ed. Rev. Philosophical Library, Inc., New York, 1956. 400 p. $10.00.

FROM THE USER's point of view, this worthy publication in 400 pages covers a large part of the field of carbon steels briefly but well.

The conciseness of the book will appeal to those who are primarily concerned with steel and its use, but even more it will appeal to those for whom steel is but one of several metals used constantly. The latter group includes such people as civil engineers, mechanical engineers, mechanics, inspectors, executives, purchasing agents. Here in a mere paragraph or two they can learn much of practical value about this universally used metal without being overwhelmed by a multitude of details with which they are not concerned.

Naturally, the author has found it necessary to set limits to his work. It is mainly about carbon steels – their compositions, properties, specifications, tests, limitations, failures. Stainless steel and heat treatable alloy steels receive little more than casual mention as materials which are used when carbon steels are not suitable. Steelmaking processes are mentioned only to the extent they affect the properties of the steel made. In the four chapters devoted to heat treating and the one devoted to welding the properties of the metal are discussed in detail. Little emphasis is placed on heat treating and welding processes. Other processes such as forging, forming, riveting, machining, are treated similarly.

Much attention is given to suitable and unsuitable composition ranges and their correlation with mechanical and physical properties. There are chapters on specifications, cold finished (bright) and free-machining steels, steels for use at elevated temperatures, and selection of steel. The author places much emphasis on testing, such as tensile, hardness, and impact tests, and an entire chapter emphasizes the prevalence and dangers of fatigue failures. Many charts and tables refer to fatigue testing. Among the testing procedures outlined in this practical book are those for the testing of needles and instrument pivots.

A few typical paragraph headings are "The Effect of Nitrogen in Steel", "The Strain-Time Creep Curve", "Prevention of Fretting Corrosion", "Fillet Weld Inspection Test", and "Fatigue Resistance Versus Damping Capacity".

In addition to the 138 illustrations, the book contains many tables and charts, which emphasize important properties, show the superiority of one material over another, or show failures resulting from use of unsuitable material or processing.

The book is a revision of earlier editions. The material relating to TTT-curves, end-quench hardenability testing, gases in steel and transition temperatures, has been revised bringing it up to today's level of knowledge and practice.

The author is a practical-minded British consultant. Following the British custom, he gives strengths in long tons (2240 psi.) unless he quotes from some source which uses psi. Likewise, Centigrade temperatures are more frequently given than Fahrenheit. However, there need be little fear that being of foreign origin, the data will not apply to American carbon steel. Similar compositions are used in both countries and properties are not different merely because of an intervening ocean.

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Superpurity Aluminum

*By E. A. BLOCH and P. H. MULLER**

Aluminum 99.99+% pure is made in tonnage for about twice the price of commercial (99.0+) metal. Its uses depend on improved conductivity, corrosion resistance, reflectivity and finish. It is made in a three-layer cell by electrolysis of Al-Cu alloy through a fusible electrolyte of mixed fluorides. Metal of 99.999% purity can be produced by a special technique. (A general, C23p; Al-a, 17-7)

ASIDE FROM THE precious metals and mercury, the commercial ones at the turn of the century could hardly be called "pure". Perhaps lead and tin came closest to that definition. The old lead refining processes able to recover the valuable silver occurring in most ores were sufficient to remove nearly all the other impurities, giving lead 99.85% pure. Tin oxide is reduced at low temperatures to purity of 99.85% or better. It required the generation of large blocks of cheap electricity before copper was available with less than 0.25% total impurities – except from certain favored locations such as Lake Superior where metal analyzing 99.90 copper plus silver could be made. Electrolytically refined zinc, 99.98%, also came in the early part of this century; the distilled zinc formerly available (unless double distilled) usually carried considerable lead – a great deal of it as much as 1.5%. Wrought iron of course carried a lot of slag; steel a lot of carbon and deoxidizers. Aluminum, the latest of our tonnage metals, analyzes 99.0 min. Al in its commercial grade, impurities being largely iron and silicon plus small fractions of copper, zinc and manganese.

None of these came anywhere near the superpurity materials now demanded for atomic reactor elements, for example. Without going to that extreme, we find that world-wide industry is now consuming thousands of tons of metals a year whose purity ranges between 99.95 and 99.995%. In general, such materials have improved electrical and thermal conductivity, resist corrosion better and work more readily; on the other hand their tensile strength and hardness are deficient.

This article will endeavor to state the properties, uses, and method of preparing aluminum with only 0.01% total impurity. It has several advantages so that the Free World now consumes about 13,000 short tons of it per year.†

Properties of Superpurity Aluminum and Its Alloys

The higher degree of purity of this 99.99+% aluminum (trade-named "Raffinal") imparts noticeably different properties from those of commercial aluminum, namely, greater ductility, better electrical conductivity, increased chemical stability against many agents, and better reflecting power. It also yields optically purer oxide films when anodized. Very small additions of iron and copper reduce the stability of superpurity aluminum against many chemical agents. Magnesium has hardly any influence up to 0.6%, and zinc, silicon and manganese are also innocuous up to about 0.4%.

As noted in American Society for Testing Materials' standard specification B 233-55, the electrical conductivity of rolled aluminum rods

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†Compagnie de Produits Chimiques et Electrometallurgiques Alais, Froges et Camargue (Pechiney) at its plant at St. Jean de Maurienne in Savoie, France, and Aluminium-Industrie-Aktien-Gesellschaft (A.I.A.G.) at Neuhausen am Rheinfall in Switzerland, both produced this commercially since the early 1930's. Limited quantities were made in the United States, and in Canada since 1953. Germany is a leading producer, making 2750 to 3300 short tons yearly. Aluminum Foils, Inc., of Jackson, Tenn., has licensed the A.I.A.G. process and will start producing this year.

Table I – Properties of Aluminum, Raffinal and Reflectal

Condition	0.2% Yield Strength, 1000 Psi.	Tensile Strength, 1000 Psi.	Elongation, % in 10 D.*	Brinell Hardness
Aluminum 99.5 (Balance mostly Si and Fe)				
Soft	2.8– 7	10 –14	30–40	18–25
Half hard	11.5–18.5	13 –21	5–20	25–40
Hard	17 –23	18.5–26	2– 8	35–45
Extruded	3.5– 7	10 –14	20–35	18–28
Raffinal (99.99+)				
Half hard	8.5–13	10 –14	10–30	20–25
Hard	13 –17	14 –18.5	4– 6	25–35
Extruded	2 – 4	5.5– 8.5	30–50	12–16
Reflectal-5 (Al plus 0.2 to 1.0% Mg)				
Half hard	13 –17	15.5–20	10–15	25–35
Hard	17 –20	18.5–21.5	8–12	30–40
Reflectal-20 (Al plus 1.5 to 2.5% Mg)				
Half hard	23 –27	27 –31.5	5–10	55–65
Hard	27 –31.5	31.5–35.5	3– 8	60–70
Reflectal-107 (Al plus 0.2 to 1.0% Si and 0.2 to 1.0% Mg)				
Hard	21.5–35.5	28.5–42.5	5–15	80–100

*Gage length = 10 diameters for rod for $11.3\sqrt{F}$ for sheets, where F is the cross-sectional area.

(EC grade, so called) for electrical purposes, analyzing about 99.5% Al, is from 61.3 to 61.8% of that of the international annealed copper standard. The superpurity aluminum has conductivity equal to 64.9% of the copper standard, or 37.7 m./ohm sq. mm. as expressed in c.g.s. units. Small amounts of foreign metals reduce the conductivity, especially manganese (Fig. 1).

An addition of suitable elements will considerably increase the strength and hardness of superpurity aluminum without noticeably affecting its corrosion resistance, reflecting power, and suitability for anodizing. The Swiss company and its licensees are selling alloys containing Mg and Mg-Si based on "Raffinal" under the registered trade mark "Reflectal". Nominal compositions and mechanical properties are given in Table I.

Additions of magnesium yield alloys which cannot be heat treated but which can easily be cold worked by bending, hammering, spinning, deep drawing and stamping. Their strength improves with increasing magnesium content and cold work. This does not impair its superior adaptability to anodizing.

The alloy with magnesium and silicon (Reflectal-107) can be heat treated and aged to tensile strength as high as 42,000 psi. and Brinell hardness of 100. It is now available in Europe as rods, bars, sections and wire. Extruded shapes may be hot formed by die pressing and can then be given a solution heat treatment followed by quenching and artificial aging. It can be machined in the heat treated condition. Prior to chemical or electrolytic brightening the parts must be fully heat treated.

Applications

Reflectivity of Raffinal and Reflectal is exceedingly high, as can be seen by Fig. 2. It varies considerably according to surface finish, as follows:

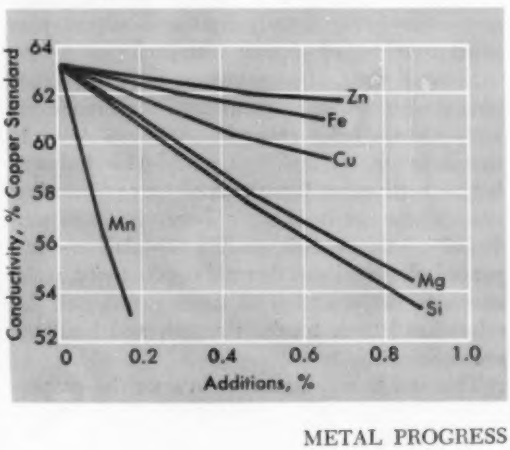
Surface Finish	Reflectivity
As rolled	76-80%
Mechanically polished	80-83
Electrolytically polished and anodized	83-85
Fine wire brushed	67-68

This very high reflectivity has found a wide range of applications. The surfaces may be electrolytically polished and anodized without their reflecting power being noticeably reduced. They are even very resistant against the highly polluted air in industrial districts and have, if properly maintained, a very long life at high performance. Figure 2 illustrates this property.

Widespread uses are also made in ornamental trim, door handles, window frames and automobile hardware. Further applications are gratings, railings, furniture fittings, fruit bowls, lighters, automatic pencils and pens – all brightened, anodized and very often colored.

Much costume jewelry can be made, such as

Fig. 1 – Effect of Alloying Additions on Electrical Conductivity of Superpurity (99.99%) Aluminum



bracelets and necklaces, polished, anodized, and gold colored, thus replacing gilded articles; the hard oxide film is much better than the gilding, which is not resistant to abrasion. An important item in Switzerland is watch cases, stamped or machined from extruded tubes, turned with diamond tools, and jewelry finished (Fig. 3).

Its good corrosion resistance recommends superpurity aluminum to the chemical industry. It is, for instance, resistant to sodium hypochlorite ($NaClO$) bleaching solutions. Even hydrochloric acid attacks it only very slowly. Its price is about twice that of commercial aluminum, so its suitability and economic efficiency have to be considered.

More recently foil rolled from superpurity aluminum is used in the fabrication of electrolytic condensers, the quality of which depends mainly on the purity of the aluminum anode. Among the usual impurities in ordinary aluminum, iron is particularly damaging; the shelf-life of the condenser decreases with increasing iron content, particularly in warm storage. In order to enlarge the active surface (and consequently increase the capacity) the anode foil is usually chemically or electrically etched.

Fig. 2 – A Workman Sees Himself in a Concave Mirror of Reflectal

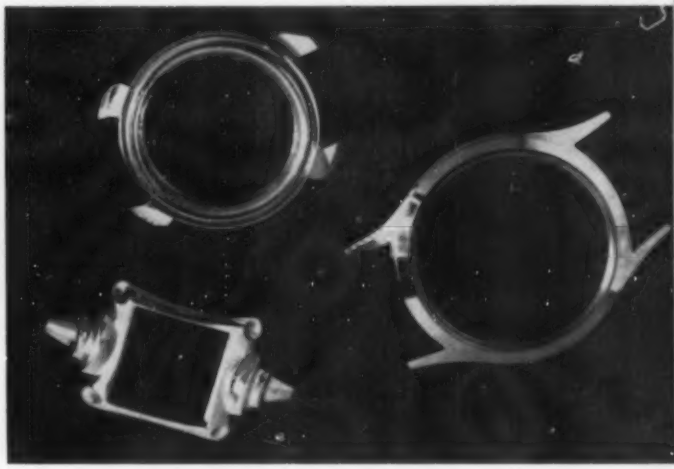


Fig. 3 – Cases for Wrist Watches Made of Superpurity Aluminum

The extremely high-purity aluminum which may be obtained by the A.I.A.G. process has interested men in the electronics fields for the manufacture of transistor equipment requiring aluminum of more than 99.999% purity.

Superpurity aluminum and its alloys have, therefore, secured applications which hitherto had been either closed to aluminum or could not be supplied reliably. We confidently expect further uses and a considerable increase of consumption in the near future.

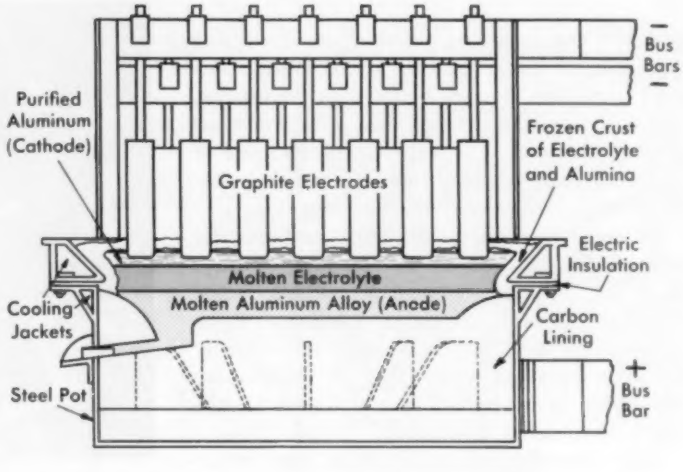
Method of Manufacture

So much for the new product and its possibilities. Let us now say a word about the method of manufacture – first noting some previous attempts to purify aluminum metal on a large scale.

Historical Note – As is well known, the electrolysis of purified alumina in a fused bath of cryolite (sodium-aluminum fluoride) was discovered independently and almost simultaneously in 1886 by Paul Heroult, the Frenchman, and Charles M. Hall, the American. Using this process – now universal – the normal output of the cell will analyze 99.0% aluminum or better, the impurities being principally iron and silicon picked up from electrodes, bath and furnace lining.

As early as 1901, William Hoopes, chief electrical engineer of Aluminum Co. of America, turned his attention to a further refining of this commercial product, but the process was not perfected until 1919 with the help of F. C. Frary and J. D. Edwards of the research staff. The

Fig. 4 – Cross section of Hoopes' Electrolytic Refining Cell. The anode is molten aluminum-copper alloy. (From "The Aluminum Industry", Vol. I, by J. D. Edwards, F. C. Frary, and Zay Jeffries)



electrolyte consisted no longer of pure cryolite, but of a mixture of about equal parts of aluminum, sodium and barium fluorides melting somewhat above 1650° F. (900° C.). As shown in Fig. 4, the cathode and the anode metal must be insulated from each other, and this was done by water cooling the carbon walls of the cell so they were covered by a chilled crust of electrolyte. As a rule a metal of 99.8 to 99.9% purity was obtained.

Shortly thereafter, in 1932 in France, R. Gadeau of Pechiney devised an electrolyte melting at about 1400° F. (750° C.) by substituting barium chloride for barium fluoride in the mixture. At this temperature the liquid aluminum does not attack magnesite, so the cell could be lined with this refractory of low electrical conductivity. The lower operating temperature also permitted attaining a purity of 99.99% Al.

The A.I.A.G. Process – In 1935 similar results were patented by A.I.A.G. in Switzerland. The electrolyte, with an even lower melting point, consisted entirely of fluorides – in practice aiming at 18% BaF_2, 16% CaF_2, 18% NaF and 48% AlF_3. It melts at less than 1300° F. (700° C.) and has extraordinary stability and insures quiet operation of the electrolytic cells. By taking special precautions it even permits the production of superpurity aluminum of 99.999%.

The first practicable refining cell of the A.I.A.G. consisted of an iron shell with brick lining, and bottom of carbon blocks. The busbars carrying positive current are embedded in the bottom, as shown in Fig. 5. The cell itself is subdivided by a dam or bridge into bath and forewell. The bath contains three liquid layers:

1. The heavy bottom layer consists of an Al-Cu, Al-Fe or Al-Zn alloy forming the anode; it has a density of about 3.2 g. per cc.

2. The electrolyte (intermediate layer) is composed of fluorides as above noted with an approximate density of 2.5 g. per cc.

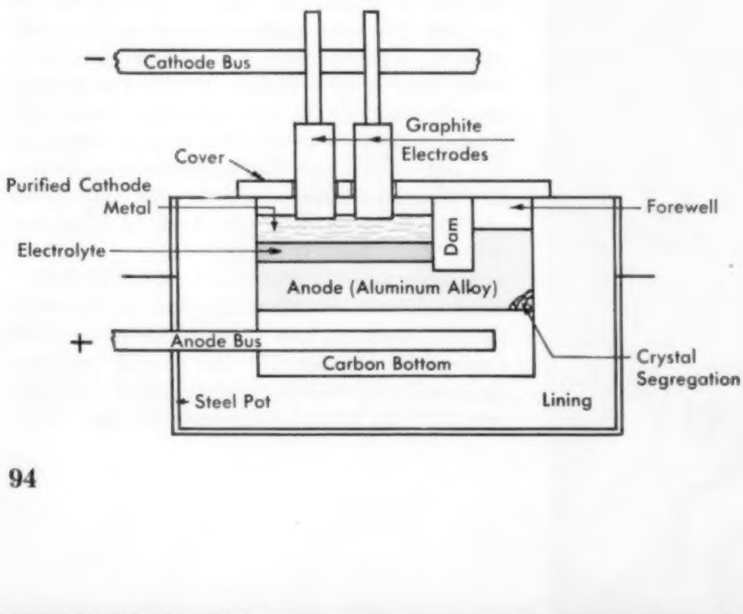


Fig. 5 – Cross-Sectional Diagram of Early Cell Used by the Swiss Firm A.I.A.G. to Produce Superpurity Aluminum

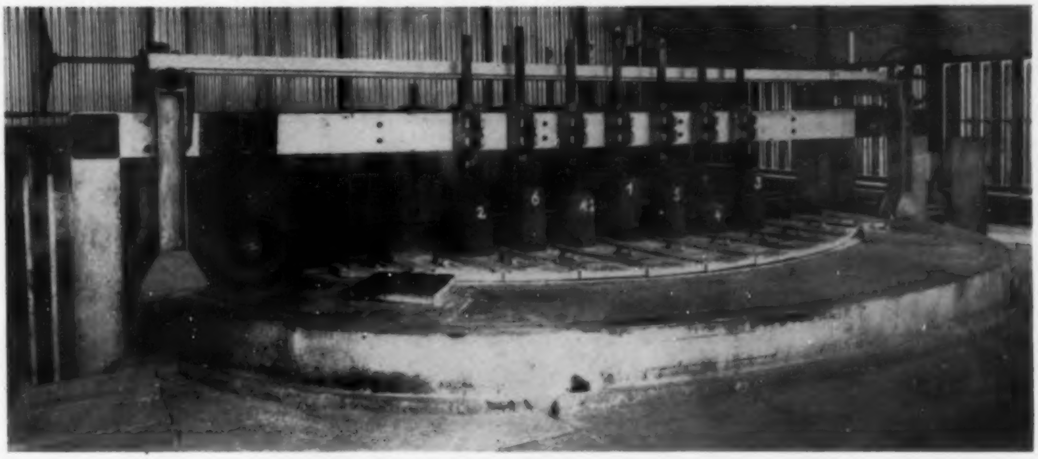


Fig. 6 – Photograph of 40,000-Amp. Cell of Recent Design

3. The top layer consists of superpurity aluminum acting as cathode. Its density is 2.3 g. per cc. at the working temperature of the cell (1365° F. or 740° C.).

Graphite electrodes dip into the high-purity aluminum layer and carry off the electric current. The cell voltage is about six volts. The cell has an insulated lid to reduce the loss of heat.

A number of these cells are arranged in series and connected to an electric generator. As the current flows the aluminum is transferred from the impure anode metal below, through the electrolyte to the cathode where it collects as a pure liquid. The more electronegative impurities, such as silicon, iron and copper, remain in the anode while the more electropositive impurities remain dissolved in the electrolyte. From time to time, as it collects, some of the superpurity aluminum is removed, while ordinary virgin aluminum or scrap is added to the forewell. The impurities gradually accumulate in the anode metal and after reaching a certain concentration segregate in the form of crystals at the cooler corners of the forewell.

With such a cell, metal of 99.990 to 99.998% purity can be produced – 99.999% if special precautions are taken.*

Production by A.I.A.G. began in 1936 in cells using 8000-amp. currents. In following years the current intensity was not increased beyond 16,000 to 18,000 amp. One reason was the small demand for superpurity metal; another was the difficulties experienced in the design and operation of the cells. Reduction of alumina in largest sized furnaces of conventional design offers no unusual difficulties from distortion of the shell in long runs. In the three-layer electrolytic process, however, small fissures in the brickwork caused by thermal distortion will permit leakage of electrolyte and bulge the cell. Once the cathode metal is contaminated by impurities it will take days, even weeks, to regain the required quality of at least 99.99% purity. In the meantime the cell is really out of production, although the operating costs continue.

On the strength of many years' experience A.I.A.G. has recently increased the current to 24,000 and even 40,000 amp., thus improving the efficiency of the process considerably. Figure 6 shows such a cell of 40,000 amp.; it will be noted that it is oval in plan. As with the conventional alumina reduction process, labor and power consumption can be considerably lowered with increasing amperage. While the usual 16,000 to 20,000-amp. cells have a power consumption of about 8.2 kw-hr. per lb. of metal produced, a 40,000-amp. cell requires only about 7.3 kw-hr. per lb.

Electrodes – Obviously the conditions prevailing in the three-layer refining process differ entirely from those of the electrolytic reduction of alumina. In the latter the positive carbon electrodes dip into the bath from above and take an active part in the reactions – in fact being consumed according to the reaction

$$Al_2O_3 + 3\,C = 2\,Al + 3\,CO$$

In the refining cells the *negative* electrodes serve as current leads only. Although they are normally graphite blocks, and do not take an active part in the refining process, they are nevertheless oxidized in the air above the bath. Electrode

*Patent application filed in U.S.A.

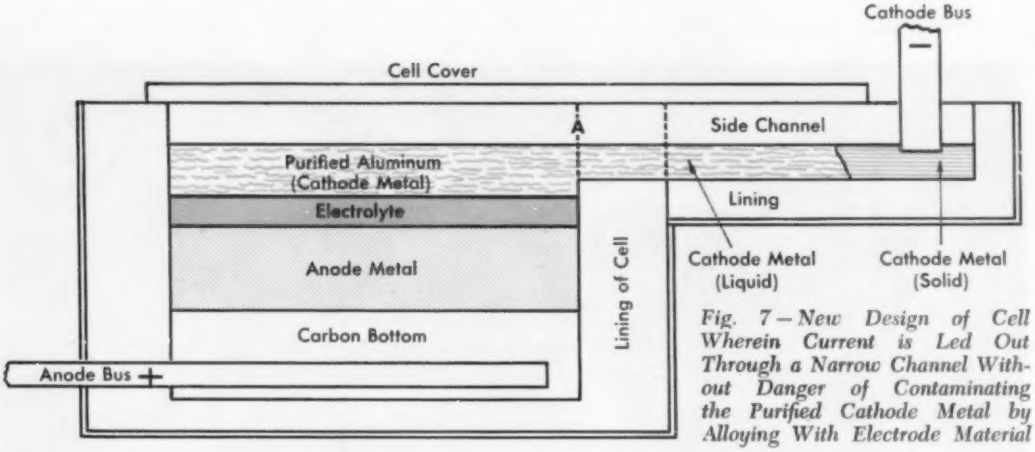


Fig. 7 – New Design of Cell Wherein Current is Led Out Through a Narrow Channel Without Danger of Contaminating the Purified Cathode Metal by Alloying With Electrode Material

consumption can reach 0.015 to 0.030 lb. per lb. of superpurity aluminum produced, depending on the quality of graphite and the mode of operation.

This loss can be reduced considerably by adequate treatment – for instance by impregnating them with a mixture of sodium tetraborate and ammonium phosphate. Even such electrodes are not quite satisfactory, because the impregnation has to be frequently repeated to be really efficient. Moreover the lower ends of the electrodes have to be cleaned periodically of the impurities originating from the electrolyte, which again increases the labor costs. These electrodes have the further disadvantage of causing a voltage drop of 0.4 to 0.6 volt, connections included, which unnecessarily increases the power consumption.

To avoid these handicaps, numerous tests with metallic cathode connections have been made. This means that the negative aluminum busbars will be immersed directly in the cathodic metal layer, yet there must be no alloying or the object of the process would be defeated. This is avoided by providing two side channels which extend out far enough so the cathode connection is made in solidified metal. (See Fig. 7). Even this solution has its difficulties since the "pinch effect" at position A may contract the liquid metal so much that the current is interrupted. This can be overcome by giving the channel a special shape.*

In such a cell two small forewells are provided wherein fresh aluminum for refining can be added to the anode metal.

Material Balance – Suppose such a cell is fed with virgin metal of 99.0% Al. The impurities, mostly Fe and Si, accumulate in the anodic layer, which can continue without disturbing the operation of the cell until the concentrations have reached 4 to 6% Fe and 6 to 8% Si. (Other impurities such as Cu, Zn and Ti are of minor importance provided the feed material does not contain contaminated scrap or alloy.)

After reaching the above limits, alloys of about the following composition start crystallizing in the cooler parts of the cell: 6 to 12% Si, 8 to 16% Fe, 12 to 25% Cu, 2 to 5% Mn, 1 to 5% Zn, Al remainder.

These crystals must be removed from the forewell periodically. Although some of the metallic values can be recovered, they represent a considerable cost from the losses of copper and aluminum. The material balance is roughly

Going in:		
Feed metal (95% Al)	115.0 lb.	
Electrolyte	4.0	
Total	119.0	
Coming out:		
Raffinal (99.99+Al)		100 lb.
Waste		11.5 lb.
Dross:		
Al recovered	2.0	
Al-free dross	4.0	6.0 lb.
Losses		1.5 lb.
Total		119.0 lb.

It is possible to use aluminum scrap as feed metal. This, of course, leads to an increase of the segregation products, and is only of interest if suitable scrap at a low price can be used. Contrary to other scrap recovery processes, copper-containing scrap is welcome.

It is hoped that this statement of properties and methods of production, now commercial, will attract the attention of many men in the metal industries whose problems may be solved by this metal of moderate price and remarkably high conductivity, reflectivity and finishing capabilities.

*Patent application filed in U.S.A.

A.I.S.I. Standard Alloy Steel Compositions[(a)]

A.I.S.I. List as of March, 1957

Openhearth and Electric Furnace Alloy Steels

(Bars, billets, blooms and slabs up to 200 sq. in., 18 in. wide or 10,000 lb.)

A.I.S.I. Number (b)	C	Mn	Ni	Cr	Mo
1330	0.28-0.33	1.60-1.90	....	....	....
1335	0.33-0.38	1.60-1.90	....	....	....
1340	0.38-0.43	1.60-1.90	....	....	....
1345	0.43-0.48	1.60-1.90	....	....	....
TS14B35 (e)	0.33-0.38	0.75-1.00	....	....	....
TS14B50 (e)	0.48-0.53	0.75-1.00	....	....	....
E2517 (c)	0.15-0.20	0.45-0.60	4.75-5.25	....	....
3135	0.33-0.38	0.60-0.80	1.10-1.40	0.55-0.75	....
3140	0.38-0.43	0.70-0.90	1.10-1.40	0.55-0.75	....
E3310 (c)	0.08-0.13	0.45-0.60	3.25-3.75	1.40-1.75	....
4012	0.09-0.14	0.75-1.00	....	....	0.15-0.25
4023	0.20-0.25	0.70-0.90	....	....	0.20-0.30
4024 (d)	0.20-0.25	0.70-0.90	....	....	0.20-0.30
4027	0.25-0.30	0.70-0.90	....	....	0.20-0.30
4028 (d)	0.25-0.30	0.70-0.90	....	....	0.20-0.30
4032	0.30-0.35	0.70-0.90	....	....	0.20-0.30
4037	0.35-0.40	0.70-0.90	....	....	0.20-0.30
4042	0.40-0.45	0.70-0.90	....	....	0.20-0.30
4047	0.45-0.50	0.70-0.90	....	....	0.20-0.30
4063	0.60-0.67	0.75-1.00	....	....	0.20-0.30
4068	0.63-0.70	0.75-1.00	....	....	0.20-0.30
4118	0.18-0.23	0.70-0.90	....	0.40-0.60	0.08-0.15
4130	0.28-0.33	0.40-0.60	....	0.80-1.10	0.15-0.25
4135	0.33-0.38	0.70-0.90	....	0.80-1.10	0.15-0.25
4137	0.35-0.40	0.70-0.90	....	0.80-1.10	0.15-0.25
4140	0.38-0.43	0.75-1.00	....	0.80-1.10	0.15-0.25
TS4140	0.38-0.43	0.80-1.05	....	0.90-1.20	0.08-0.15
4142	0.40-0.45	0.75-1.00	....	0.80-1.10	0.15-0.25
4145	0.43-0.48	0.75-1.00	....	0.80-1.10	0.15-0.25
4147	0.45-0.50	0.75-1.00	....	0.80-1.10	0.15-0.25
4150	0.48-0.53	0.75-1.00	....	0.80-1.10	0.15-0.25
TS4150	0.48-0.53	0.80-1.05	....	0.90-1.20	0.08-0.15
TS43BV12 (f)	0.08-0.13	0.75-1.00	1.65-2.00	0.40-0.60	0.20-0.30
4320	0.17-0.22	0.45-0.65	1.65-2.00	0.40-0.60	0.20-0.30
4337	0.35-0.40	0.60-0.80	1.65-2.00	0.70-0.90	0.20-0.30
E4337	0.35-0.40	0.65-0.85	1.65-2.00	0.70-0.90	0.20-0.30
4340	0.38-0.43	0.60-0.80	1.65-2.00	0.70-0.90	0.20-0.30
E4340	0.38-0.43	0.65-0.85	1.65-2.00	0.70-0.90	0.20-0.30
46B12 (e)	0.10-0.15	0.45-0.65	1.65-2.00	....	0.20-0.30
4615	0.13-0.18	0.45-0.65	1.65-2.00	....	0.20-0.30
4617	0.15-0.20	0.45-0.65	1.65-2.00	....	0.20-0.30
4620	0.17-0.22	0.45-0.65	1.65-2.00	....	0.20-0.30
4621	0.18-0.23	0.70-0.90	1.65-2.00	....	0.20-0.30
4640	0.38-0.43	0.60-0.80	1.65-2.00	....	0.20-0.30
4720	0.17-0.22	0.50-0.70	0.90-1.20	0.35-0.55	0.15-0.25
4815	0.13-0.18	0.40-0.60	3.25-3.75	....	0.20-0.30
4817	0.15-0.20	0.40-0.60	3.25-3.75	....	0.20-0.30
4820	0.18-0.23	0.50-0.70	3.25-3.75	....	0.20-0.30
5015	0.12-0.17	0.30-0.50	....	0.30-0.50	....
5046	0.43-0.50	0.75-1.00	....	0.20-0.35	....
50B30 (e)	0.28-0.33	0.75-1.00	....	0.40-0.60	....
50B40 (e)	0.38-0.43	0.75-1.00	....	0.40-0.60	....
50B44 (e)	0.43-0.50	0.75-1.00	....	0.40-0.60	....
50B46 (e)	0.43-0.50	0.75-1.00	....	0.20-0.35	....
50B50 (e)	0.48-0.53	0.75-1.00	....	0.40-0.60	....
50B60 (e)	0.55-0.65	0.75-1.00	....	0.40-0.60	....
51B60 (e)	0.55-0.65	0.75-1.00	....	0.70-0.90	....
5120	0.17-0.22	0.70-0.90	....	0.70-0.90	....
5130	0.28-0.33	0.70-0.90	....	0.80-1.10	....
5132	0.30-0.35	0.60-0.80	....	0.75-1.00	....
5135	0.33-0.38	0.60-0.80	....	0.80-1.05	....
5140	0.38-0.43	0.70-0.90	....	0.70-0.90	....
5145	0.43-0.48	0.70-0.90	....	0.70-0.90	....
5147	0.45-0.52	0.70-0.95	....	0.85-1.15	....
5150	0.48-0.53	0.70-0.90	....	0.70-0.90	....
5155	0.50-0.60	0.70-0.90	....	0.70-0.90	....
5160	0.55-0.65	0.75-1.00	....	0.70-0.90	....
E50100	0.95-1.10	0.25-0.45	....	0.40-0.60	....
E51100	0.95-1.10	0.25-0.45	....	0.90-1.15	....
E52100	0.95-1.10	0.25-0.45	....	1.30-1.60	....
6120	0.17-0.22	0.70-0.90	....	0.70-0.90	0.10 min. V
6150	0.48-0.53	0.70-0.90	....	0.80-1.10	0.15 min. V
8115	0.13-0.18	0.70-0.90	0.20-0.40	0.30-0.50	0.08-0.15
81B45 (e)	0.43-0.48	0.75-1.00	0.20-0.40	0.35-0.55	0.08-0.15
8615	0.13-0.18	0.70-0.90	0.40-0.70	0.40-0.60	0.15-0.25
8617	0.15-0.20	0.70-0.90	0.40-0.70	0.40-0.60	0.15-0.25
8620	0.18-0.23	0.70-0.90	0.40-0.70	0.40-0.60	0.15-0.25
8622	0.20-0.25	0.70-0.90	0.40-0.70	0.40-0.60	0.15-0.25
8625	0.23-0.28	0.70-0.90	0.40-0.70	0.40-0.60	0.15-0.25
8627	0.25-0.30	0.70-0.90	0.40-0.70	0.40-0.60	0.15-0.25
8630	0.28-0.33	0.70-0.90	0.40-0.70	0.40-0.60	0.15-0.25
8637	0.35-0.40	0.75-1.00	0.40-0.70	0.40-0.60	0.15-0.25
8640	0.38-0.43	0.75-1.00	0.40-0.70	0.40-0.60	0.15-0.25
8642	0.40-0.45	0.75-1.00	0.40-0.70	0.40-0.60	0.15-0.25
8645	0.43-0.48	0.75-1.00	0.40-0.70	0.40-0.60	0.15-0.25
86B45 (e)	0.43-0.48	0.75-1.00	0.40-0.70	0.40-0.60	0.15-0.25
8650	0.48-0.53	0.75-1.00	0.40-0.70	0.40-0.60	0.15-0.25
8655	0.50-0.60	0.75-1.00	0.40-0.70	0.40-0.60	0.15-0.25
8660	0.55-0.65	0.75-1.00	0.40-0.70	0.40-0.60	0.15-0.25
8720	0.18-0.23	0.70-0.90	0.40-0.70	0.40-0.60	0.20-0.30
8735	0.33-0.38	0.75-1.00	0.40-0.70	0.40-0.60	0.20-0.30
8740	0.38-0.43	0.75-1.00	0.40-0.70	0.40-0.60	0.20-0.30
8742	0.40-0.45	0.75-1.00	0.40-0.70	0.40-0.60	0.20-0.30
8822	0.20-0.25	0.75-1.00	0.40-0.70	0.40-0.60	0.30-0.40
9255 (g)	0.50-0.60	0.70-0.95	....	....	....
9260 (g)	0.55-0.65	0.70-1.00	....	....	....
9261 (g)	0.55-0.65	0.75-1.00	....	0.10-0.25	....
9262 (g)	0.55-0.65	0.75-1.00	....	0.25-0.40	....
E9310	0.08-0.13	0.45-0.65	3.00-3.50	1.00-1.40	0.08-0.15
E9314	0.11-0.17	0.40-0.70	3.00-3.50	1.00-1.40	0.08-0.15
94B15 (e)	0.13-0.18	0.75-1.00	0.30-0.60	0.30-0.50	0.08-0.15
94B17 (e)	0.15-0.20	0.75-1.00	0.30-0.60	0.30-0.50	0.08-0.15
94B30 (e)	0.28-0.33	0.75-1.00	0.30-0.60	0.30-0.50	0.08-0.15
94B40 (e)	0.38-0.43	0.75-1.00	0.30-0.60	0.30-0.50	0.08-0.15
9840	0.38-0.43	0.70-0.90	0.85-1.15	0.70-0.90	0.20-0.30
9850	0.48-0.53	0.70-0.90	0.85-1.15	0.70-0.90	0.20-0.30
Standard Nitriding Steel (h)					
....	0.38-0.43	0.50-0.70	....	1.40-1.80	0.30-0.40

Note *(a)* — All chemical ranges and limits are subject to the standard variations for check analysis over or under specification.

Note *(b)* — Numbers with prefix E are generally made in basic electric furnaces and unless otherwise noted the following specifications hold: phosphorus 0.025% max., sulphur 0.025% max., silicon 0.20 to 0.35%.

Numbers without letter prefix are ordinarily made in basic openhearth furnaces and unless otherwise noted the following specifications hold: phosphorus 0.040% max., sulphur 0.040% max., silicon 0.20 to 0.35%.

Specification limits for the acid electric and acid openhearth processes are: phosphorus 0.050% max., sulphur 0.050% max., silicon 0.15 to 0.35%.

In all processes the maximum allowable quantities of unspecified and incidental elements are as follows: 0.35% copper, 0.25% nickel, 0.20% chromium and 0.06% molybdenum.

Numbers with prefix TS represent tentative standard steels.

Note *(c)* — When this steel is made in openhearth furnaces the manganese is 0.45 to 0.60%.

Note *(d)* — Resulphurized steels; sulphur is 0.035 to 0.050% except in 8641 where it is 0.040 to 0.060%.

Note *(e)* — This steel can be expected to have 0.0005% min. boron.

Note *(f)*—This steel contains 0.03% min. vanadium and can be expected to have 0.0005% min. boron.

Note *(g)* — Silico-manganese steels; silicon range is 1.80 to 2.20%.

Note *(h)*—The standard nitriding steel has silicon 0.20-0.40 and aluminum 0.95-1.30.

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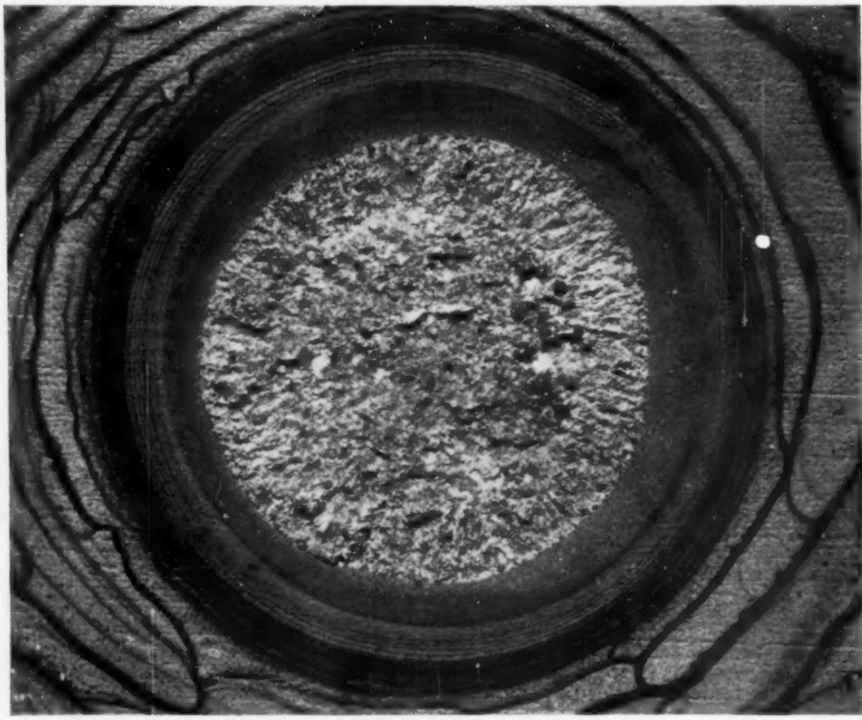

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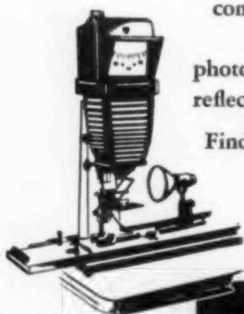

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New Magnesium Alloys for High Temperature

*By T. E. LEONTIS**

Addition of thorium up to 4% (in combination with Zr, Mn and Zn) produces magnesium castings, sheet and extrusions of superior short-time tensile properties up to 800 or 900° F., markedly better creep resistance up to 700° F., and raises the temperature limit of utility above 600° F. as well as extends the range of applications in the 300 to 500° F. range. (Q general, 2-12, 2-10; Mg, *Zr*, AD-n, AD-q)

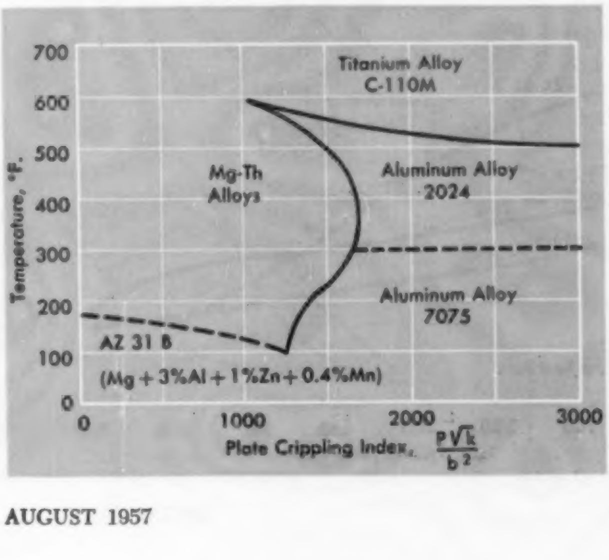
In selecting metals for aircraft engines, missiles and air-borne equipment, the trend toward extraordinarily high speed is emphasizing the matter of strength at high temperatures as an inseparable companion to strength at light weight. It is not surprising therefore that much work has been done on magnesium alloys to improve their properties. It also so happened that in 1948 the Atomic Energy Commission asked for such alloys which would have the additional property of low neutron capture. This combination of circumstances resurrected interest in the magnesium-thorium alloys, known since the late 1930's to have useful age hardening capability.

The aim was to supplement the existing groups of magnesium alloys useful at respective temperature levels: *(a)* magnesium-aluminum-zinc for exposure temperatures up to 300° F., as in reciprocating engines and *(b)* magnesium-misch metal-zirconium for temperatures up to 500° F., as in jet engines. The aim was to create alloys useful to 700° F. for moderately long exposure.

This paper will recount very briefly the studies which indicate that magnesium alloys with thorium as principal alloying element will meet this new demand.

As evidence supporting the last statement, Fig. 1 is presented which

Fig. 1 — Plate-Crippling Index Versus Temperature, Indicating That Mg-Th Alloys Have Extended the Range of Usefulness in the 300 to 500° F. Range



*Chief of Castings Section in the Metallurgical Laboratory of Dow Chemical Co., Midland, Mich. This article is a much shortened version of a paper read before the A.E.C.-A.S.M. Conference on Thorium in Cleveland, Oct. 11, 1956, the whole proceedings of which will be available in book form from the A.S.M. later this year.

shows how the magnesium-thorium alloys compare with such competitive materials as aluminum alloys 7075 and 2024 and titanium alloy C-110 M, on the basis of a structural "index" which takes the effect of dimensions out of the design problem – that is to say, equivalent situations give the same value of structural index, regardless of absolute size.

This plate-crippling index is computed from the edge load P, the width b of the plate and a factor k relating to the nature of clamping or restraint along the edges. The formula is

$$\text{Index} = P\sqrt{k} \div b^2$$

The comparisons in Fig. 1 are on an equal weight basis and show, for each value of structural index and temperature, the material that will give the lightest structure capable of carrying the necessary load. Low values of index correspond to lightly loaded structures; higher values represent bulkier, more heavily loaded structures. For purposes of orientation, a long plate designed to span a width of 15 in. between simple edge supports, and carrying a load of 100,000 lb. in compression parallel to its length, has a structural index value of 890. Fuselage designs often figure in the neighborhood of 200, while a heavy wing structure may have an index of about 2000.

It should be noted how the conventional Mg-Al-Zn alloy AZ 31 B has a limited temperature range of usefulness, and loses out in competition with 7075 for structural index values above about 1200, even at atmospheric temperatures. The introduction of the thorium alloy series, however, has raised the temperature limit of utility to 600° F. and even higher. At the same time, the range of structural index (that is, the range of applications) for which the magnesium alloy provides the lightest structure has not merely been maintained but has been substantially increased in the 300 to 500° F. range.

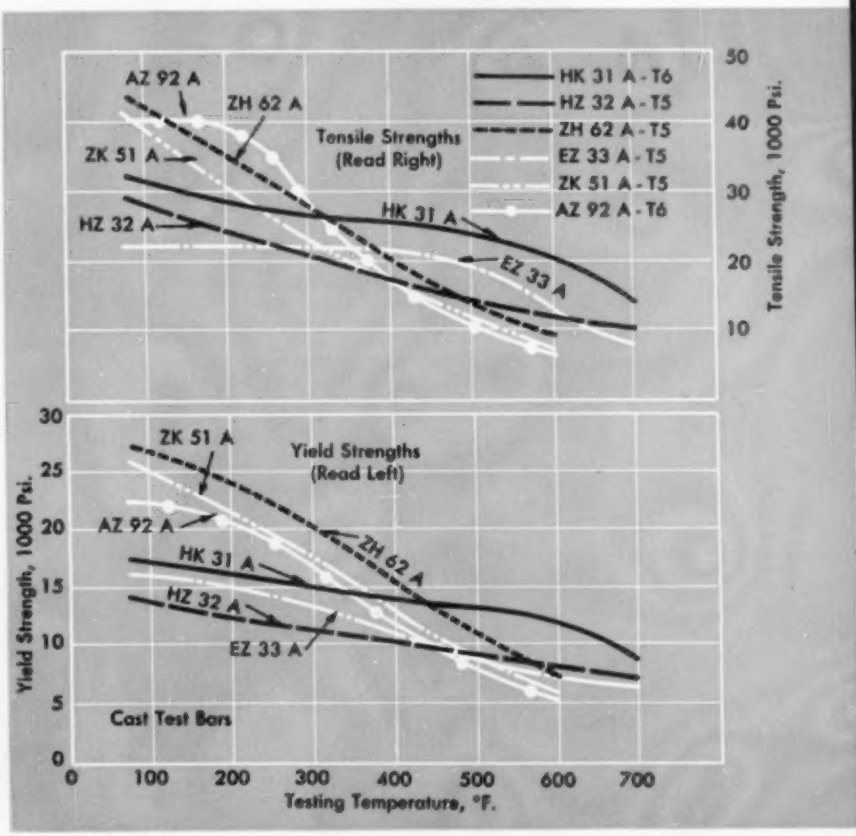
Physical and Mechanical Properties

A very brief outline of a large amount of laboratory work on the Mg-Th and the Mg-Th-Zr alloys will now be given. Following that will be a much more specific description of the alloys now commercial or recommended.

Density – The density of thorium is 11.7 as compared to 1.74 for magnesium. Yet the rapid increase in density with increasing thorium content is not of practical significance, because commercial Mg-Th alloys contain only 1 to 3 weight % Th. The densities of the resulting alloys are no greater than most of the older magnesium alloys containing aluminum and zinc as the principal alloying constituents.

Grain Size – Thorium has no pronounced effect on grain size. More than 6% Th is required to suppress the formation of columnar grains in castings, and even at 10 to 50% Th

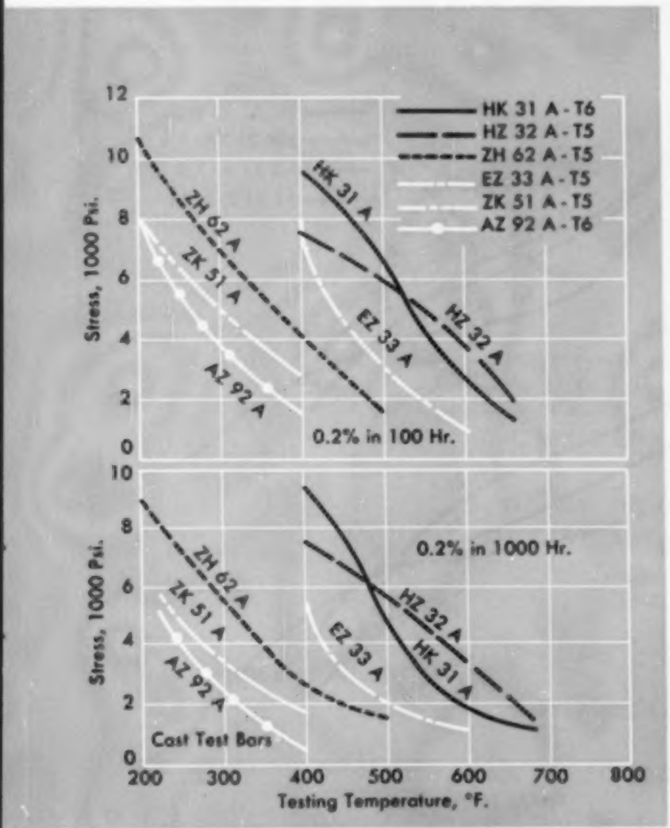
Fig. 2 – Short-Time Tensile and Yield Strengths of Alloys Shown in Table I. Alloys containing thorium are in black; the older high-temperature alloys are in white



the equiaxed grains are between 0.03 and 0.08 in. Zirconium is especially useful here. As in several other magnesium alloy systems, zirconium exerts marked grain-refining action. The columnar or coarse equiaxed grain structure of sand cast Mg-Th alloys is converted by the addition of Zr to a fine equiaxed grain structure of 0.001 to 0.002 in.

Tensile and Compressive Properties – Tensile strength of cast Mg-Th alloys in the T 6 condition* is only moderately increased with increasing thorium. However – and this is important – the alloys retain their strength up to at least 600° F. The reduction in grain size resulting from the addition of zirconium markedly increases the strength properties of cast Mg-Th alloys both at room temperature and at elevated temperatures. The optimum properties are obtained by solution heat treating and aging, and the addition of zirconium increases the degree of age hardening. The increased strengths are realized with no loss in ductility – in fact alloys

Fig. 3 – Stress to Produce 0.2% Extension in 100 Hr. (Top) and 1000 Hr. in Alloys of Fig. 2



of low thorium and zirconium content actually have improved ductility over the corresponding Mg-Th binary alloys.

Extrusions are not so pronouncedly affected by zirconium, but it is noteworthy that the compressive yield increases almost linearly from about 12,000 psi. (no thorium) to 27,500 psi. (15% Th) when tested at 70° F. Furthermore the addition of 2% or more of thorium either to magnesium or the magnesium-zirconium binary results in extrusions with equivalent yield points in both tensile and compressive tests. Another important observation is the high level of ductility of Mg-Th-Zr alloys over a wide range of thorium content. Actually, ductility as measured by percent elongation in the tensile test at room temperature goes through a rather flat maximum of 22% at about 6% Th.

Creep – The outstanding characteristic of Mg-Th alloys is their resistance to creep at elevated temperatures. This willl be clearly shown in the curves later shown for specific alloys. Generally speaking, the creep resistance values of Mg-Th alloys at 500 and 600° F. are the highest observed in any magnesium alloy to date.

The addition of Zr also enhances the creep resistance at 400 and 500° F. even if, at 600°, there is little if any effect. The commercial importance of these cast alloys stems from the combination of fine grain size, high strength and creep resistance.

In extrusions the first few percent of thorium increases the creep limit much more rapidly than it does in castings. At higher thorium contents the extruded alloys do not have as high creep resistance as the cast alloys. However, the values are still exceptional for extruded magnesium alloys. Zirconium adds slightly to the creep values, especially if the extrusions are aged or given a solution heat treatment. One word of caution is necessary: Properties of wrought products are markedly affected by processing variables and it should not be assumed that

*Throughout this paper various conditions or tempers are noted by standard A.S.T.M. designations:

F	=	As fabricated
O	=	Fully annealed
T 5	=	Artificially aged only
T 4	=	Solution heat treated
T 6	=	Solution heat treated plus artificially aged
T 8	=	Solution heat treated plus cold worked plus artificially aged
H 24	=	Cold worked plus partially annealed

Table I – Thorium and Conventional Alloys for Magnesium Castings

Designation	Temper	Composition Range: Th	Zn	Zr	MM*	Tensile Properties at 70° F.: Tensile	Yield	Elong.‡
Thorium Alloys								
HK31A	T6	2.5-4.0	—	0.5-1.0	—	31,000	16,000	6
HZ32A	T5	2.5-4.0	1.7-2.5	0.5-1.0	—	29,000	15,000	8
ZH62A	T5	1.4-2.2	5.2-6.2	0.5-1.0	—	40,000	26,000	8
Conventional Alloys								
EZ33A	T5	—	2.0-3.5	0.5 min.	2.5-4.0	23,000	16,000	3
ZK51A	T5	—	3.6-5.5	0.5-1.0	—	40,000	26,000	8
AZ92A	T6	—	1.6-2.4†	—	—	40,000	23,000	2

*MM represents misch metal

†Also contains 8.3-9.7 Al and a minimum of 0.1 Mn

‡% elongation in 2 in.

the optimum conditions were used in preparing the alloys in the laboratory or that they can be directly reproduced on production-scale equipment.

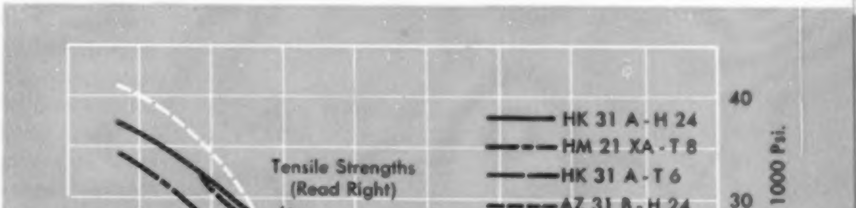
Effects of Other Additions

Manganese added to Mg-Th alloys markedly enhances the temperature resistance, and results in exceptional static strength in the range of 500 to 900° F., and high creep resistance at 500 to 700° F. No cast Mg-Th-Mn alloy has yet progressed beyond the development stage. On the other hand, rolling and extrusion ingot is cast by the direct-chill continuous process, and sheet and extruded alloys are now being produced on a semicommercial scale. The properties of the specific compositions are described further on in the text.

Zinc additions are also generally beneficial, so that higher strengths are retained in Mg-Th-Zr-Zn alloys after long exposure at temperatures over 500° F. and higher creep resistance is exhibited at increasingly higher temperatures depending on the time of loading. Specific data will be quoted later for two combinations, both of which are commercial casting alloys.

Rare Earth Metals – Cerium slightly strengthens Mg-Th alloys either cast or extruded, at the expense of some ductility. The same can be said for Mg-Th-Zr plus Ce. Unfortunately a little cerium or misch metal is definitely detrimental to the creep resistance of the Mg-Th-Zr-Zn alloys.

Fig. 4 – Short-Time Tensile and Yield Strengths of Wrought Alloys Shown in Table II, Tested as 0.040 to 0.250-In. sheet. Alloys containing thorium are in black; a comparison Al-Zn-Mn alloy in white



Commercial Alloys

Despite the large amount of work so briefly summarized above, the full potentialities of magnesium alloys containing thorium have not been realized. However, a number of compositions have advanced to the stage of commercial utilization and a greater number either are currently available on a semicommercial basis or are in an advanced stage of development.

For the production of castings (either sand or permanent mold) three alloys are available commercially, as shown at the top of Table I. HK 31 A and HZ 32 A are recommended for use at elevated temperatures. These two alloys at room temperature are quite similar. ZH 62 A alloy, on the other hand, has outstanding strength at 70° F., but it does not retain its strength as well at elevated temperatures. The other alloys noted are older compositions included in the table and graphs for comparison.

Fig. 5 – Stress to Produce 0.2% Extension in 100 Hr. (Top) and 0.5% in 100 Hr. in Alloys of Fig. 4

The short-time tensile properties of the three alloys containing thorium (black lines) are compared over a wide temperature range with those of other magnesium alloys in Fig. 2. All the results were determined on separately cast test bars, and no attempt will be made in this paper to present properties on bars sectioned from actual production castings (although such information has been determined for a variety of casting configurations by K. E. Nelson and published in the *Transactions* of American Foundrymen's Society in 1953 and 1955). The alloys used for comparison represent the various magnesium alloy systems in common use. AZ 92- A-T 6 is a high-strength alloy of the Mg-Al-Zn system; ZK 51 A-T 5 is another high-strength alloy with Zn and Zr, and EZ 33 A-T 5 is a high-temperature alloy containing rare earth metals.

The temperature resistance of Mg-Th-Zr alloys – and in fact, of Mg-MM-Zr alloys (MM symbolizing misch metal) – is clearly indicated by the curves in Fig. 2. Although AZ 92 A, ZK 51 A, and ZH 62 A have much higher strengths at room temperature, all lose their strengths rapidly with increasing temperature. HK 31 A alloy exhibits higher strength properties than HZ 32 A alloy over the entire temperature range. The position of EZ 33 A alloy with respect to HK 31 A and HZ 32 A is clearly shown. There is no question but that HK 31 A alloy has the highest short-time strength at elevated temperatures.

More striking differences among the cast alloys are to be found in their resistance to creep at elevated temperatures (Fig. 3). Limiting stress for 0.2% total extension is shown both for 100 hr. and 1000 hr. The relatively low creep resistance of the high-strength alloys AZ 92 A, ZK 51 A and ZH 62 A is clearly evident although ZH 62 A shows some advantage over the other two. Considerable improvement in creep resistance is obtained by the use of a Mg-MM-Zr alloy such as EZ 33 A, but the improvement is more pronounced in the Mg-Th-Zr alloys, HK 31 A and HZ 32 A. Although the former is superior at 400° F., the situation reverses with increasing temperature, where HZ 32 A alloy is significantly better especially when the 1000-hr. test is considered. The

crossing point in temperature is lower the longer the time of testing. Long *exposure* at 600° F. lowers the short-time yield of strength of HK 31 A alloy below that of HZ 32 A, which is evidence of the stabilizing effect of zinc in cast magnesium-thorium-zirconium alloys.

Castability – Extensive work has been reported on the castability of HK 31 A and HZ 32 A alloys and on the properties attainable in actual castings in production, and similar results are also available for ZH 62 A alloy. Space does not permit a detailed discussion of this subject; suffice it to say that satisfactory and commercially acceptable castings are being made in these alloys with perhaps a few more precautions being necessary than for Mg-Al-Zn or even Mg-MM-Zr. alloys. The properties of bars sectioned from castings bear a high ratio to those obtained in separately cast test bars.

These alloys are weldable and most of the surface treatments commonly used on magnesium alloys can be applied. In general, Mg-Th-Zr alloys are well established in the family of magnesium casting alloys and their use is expected to expand as more and more applications requiring high strength and creep resistance at elevated temperatures materialize in the future.

Wrought Alloys; Sheet and Extrusions

Sheet – The wrought magnesium alloys containing thorium now available in commercial form are listed in Table II. HK 31 A-H 24 sheet is a fully commercial mill product; the T 6 treatment is by the user. HK 31 A-O can also be obtained commercially; data for this temper are not included in this paper, the curves being for the T 6 temper. HM 21 XA-T 8 sheet and HM 31 XA-F extrusions are available commercially on an experimental basis, and the properties given in Table II for this experimental alloy should be considered as tentative.

Tensile properties of the three sheet alloys containing thorium are shown in Fig. 4 in black, where they are compared with those of the Mg-Al-Zn alloy AZ 31 B-H 24. The superiority of all the thorium-containing alloys over AZ 31 B at temperatures above 200 to 300° F. is clearly evident. HK 31 A-H 24 has the highest strength of the thorium-containing alloys up to 500° F. but then loses its superiority. The highest strengths at temperatures above 600° F. are attainable in HM 21 XA-T 8, and it appears to have structurally useful properties up to about 800 or 900° F.

The creep characteristics of these alloys, as measured by two creep parameters, are shown in Fig. 5 and follow much the same trends, except that the superiority of the thorium-containing alloys is much more pronounced than in the tensile properties. Among the Mg-Th alloys HM 21 XA-T 8 is unquestionably superior to HK 31 A in creep resistance. The advantage

Fig. 6 – Short-Time Tensile and Yield Strengths of Extruding Alloys Shown in Table II (Rods, Bars and Shapes)

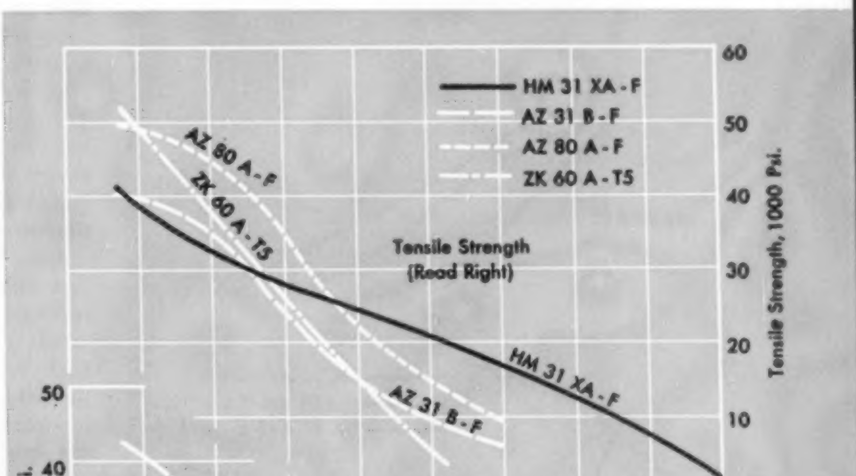


Table II – Wrought Alloys

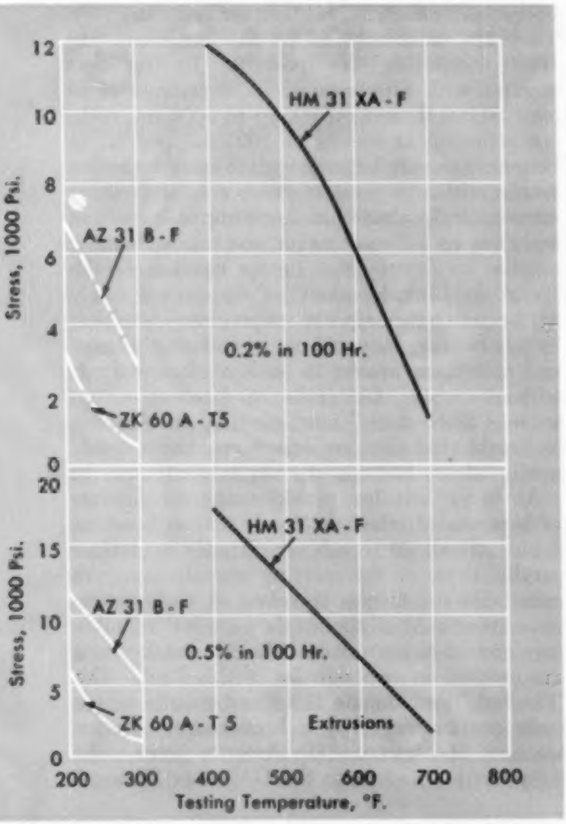
Designation	Temper	Composition Range					Tensile Properties at 70° F.			
		Th	Mn	Zr	Al	Zn	Tensile	Yield	Elong.*	C. P.†
Sheet Alloys										
HK31A	H24	2.5-4.0	—	0.45-1.0	—	—	37,000	29,000	8	25,000
HK31A	T6	2.5-4.0	—	0.45-1.0	—	—	37,000	21,000	14	15,000
HM21XA	T8	1.5-2.5	0.35-0.80	—	—	—	34,000	25,000	10	17,000
AZ31B	H24	—	0.2 min.	—	2.5-3.5	0.7-1.3	42,000	32,000	15	26,000
Extrusion Alloys										
HM31XA	F	2.5-3.5	1.2 min.	—	—	—	42,000	33,000	10	27,000
AZ31B	F	—	0.2 min.	—	2.5-3.5	0.7-1.3	38,000	29,000	15	14,000
ZK60A	T5	—	—	0.45 min.	—	4.8-6.2	53,000	44,000	11	36,000
AZ80A	F	—	0.15 min.	—	7.8-9.2	0.2-0.8	49,000	36,000	11	32,000

*% elongation in 2 in. †Compressive yield strength

in creep resistance of the T 6 condition over the H 24 temper in HK 31 A alloy is also evident.

Extruded Shapes – Figure 6 compares the tensile properties of extruded HM 31 XA-F alloy (thorium containing) with the three standard commercial extrusion alloys noted in the lower portion of Table II. Its marked advantage at temperatures above 300° F. over all the other alloys is clearly shown. ZK 60 A and AZ 80 A are high-strength extrusion alloys and are significantly better at room temperature and moderately elevated temperatures, but their strength rapidly decreases with increasing temperature. (This phenomenon was noted for the conventional high-strength casting alloys.) The creep limits shown in Fig. 7 emphasize this superiority of HM 31 XA-F alloy for long-time applications.

Fig. 7 – Stress to Produce 0.2% Extension in 100 Hr. (Top) and 0.5% in 100 Hr. in Alloys of Fig. 6



Conclusion

An attempt has been made in this paper to present the basic properties of Mg-Th alloys, and to indicate the essential characteristics of some of their commercial and semicommercial alloys. That the use of thorium as an alloying element has markedly increased the temperature range over which magnesium has structurally useful properties has been adequately demonstrated.

The wrought magnesium-thorium alloys can be formed by the usual techniques, except that somewhat higher temperatures are required. In addition, they have outstanding welding characteristics and require no subsequent stress relief. They show no evidence of stress-corrosion failure and may be protected against general corrosion by most of the available chemical surface treatment schedules.

Wrought magnesium-thorium alloys have been developed more recently than the corresponding casting alloys. Experience is being gained rapidly both in their commercial production and fabrication. Use to date has been confined essentially to experimental-scale applications but their potential as large-scale production materials appears large.

Weapons of the Future*

Guided Missiles

Since World War II development of new weapons has been rapid and continuous. Fighter aircraft will be replaced by guided missiles soon, and in something like five years the long-range ballistic missile will be with us. In turn, the pattern of defense is now determined by offensive weapons capable of delivering hydrogen bombs. The following list is arranged in order of increasing potency of the offensive weapon.

Subsonic bombers are typified by the British V-bombers, [United States' B-52 and the Russian Bison]. Operating altitudes range from 30,000 to 45,000 ft., speeds up to 550 mi. per hr. and ranges from 1500 to 6000 mi. (clear around the earth with aerial refueling facilities). Defensive weapons include conventional fighter aircraft and ground-to-air guided missiles of the first generation.

Supersonic bombers spell the end of fighter aircraft. The Russians now have them. In the United States the B-58 "Hustler" is now in test flight, and is said to fly at 1000 mi. per hr. or more (Mach 1.3). They are now "on the drawing board" in Great Britain. These aircraft have ceilings up to 75,000 ft. Defensive weapons include air-to-air or ground-to-air missiles.

Intermediate range bombardment missiles are of two classes. Missiles like the U.S. Air Forces' "Snark" cruise below 20-mi. ceiling for distances of 1500 mi. or more, at speeds up to 2000 mi. per hr. These are at least potentially vulnerable to defensive missiles, and will be replaced by the *ballistic* [high-altitude] missile of intermediate range.

In this class is the Russian ballistic missile developed from the German V-2 of World War II. [The V-2 had devices automatically correcting for altitude and instability, it went above 132 mi. high and at about 3600 mi. per hr.] No doubt the range is now about 1500 mi. and the guidance systems are improved so every other missile will fall within 15 mi. of target – approximately equal to the radius of almost total destruction by a hydrogen bomb.

In the United States, ballistic missiles of comparable ranges are the Army's "Jupiter" and the Air Forces' "Thor". In Britain there is every reason to believe that a missile of this class (or one that would be an effective defense against supersonic bombers flying as high as 20 mi.) is nearing production.

Inter-Continental Ballistic Missile (ICBM) – Under the code name of "Atlas" this is being developed by the U.S. Air Forces. Its advantages are great speed – up to 20,000 mi. per hr. – and a trajectory which might rise up to 600 mi. Range could be 10,000 mi. without much difficulty. They will probably not be available for some years, partly because so little is known about the atmospheric conditions more than 100 mi. up, but earth satellites will help to provide this information. Unsolved problems are so serious that design cannot possibly begin for another year. The official view seems to be that the ICBM will not become a working weapon before 1962 and probably not before 1964.

Defense Against Hydrogen Bombing

Appropriate defensive weapons must reach the altitudes of their target, be faster and just as maneuverable.

Fighter Aircraft – [A whole family of "Century" supersonic aircraft, F-100 to F-107, are in operation by the U.S., or about ready for delivery. They are manufactured by five American aircraft companies, are powered by turbo-jet engines with afterburners, have ceilings of at least 50,000 ft. and ranges up to 3000 mi. without refueling at speeds of 1000 mi. per hr. or better. Some are large enough to carry hydrogen bombs, although most of them are "all-weather interceptors", electronically equipped to find and close on a distant target, and release homing missiles to destroy it. In the opinion of the "Scientific Correspondent"] they are not likely to be effective against supersonic bombers, largely because they will not be sufficiently faster and cannot maneuver as well as their targets without causing their pilots to become unconscious. Since 2 to 7 min. are used in climbing to height, the effective range is comparatively small – about 100 mi. even at subsonic speeds.

Air-to-air missiles provide manned fighters with power of effective attack against bombers flying at about Mach 1. Their limitations parallel those of the carrying aircraft; they are unsuitable for targets traveling at truly supersonic speeds. At all speeds they are less valuable than ground-to-air missiles. British development has resulted in two missiles of this kind. The "Fireflash" and the de Havilland missile which seeks out its target by a heat-sensitive device are now obsolescent. [In America some publicity has been given to the GAR-1 or "Falcon"

*Extracts from two articles signed "By Our Scientific Correspondent" in *Manchester Guardian Weekly*, Feb. 28 and March 7, 1957. Reprinted by permission. Interpolations by the Editor of *Metal Progress* are enclosed in brackets [ ].

guided missile, said to be able to cope with an American B-52 or a Russian "Bison" bomber, and the "Sidewinder", a heat-seeking missile.]

Ground-to-Air Missiles – There seems to be at least two generations of these. The first generation is characterized by a range of about 20 mi. Typical British members are being produced by Armstrong-Whitworth (for naval use) and by English Electric. Similar is the United States Army's "Nike Ajax". Their range limitation implies that they would be ineffective against aircraft flying at 70,000 ft.

Little definite is known about later generations of missiles, which could knock down supersonic aircraft. The problems of design, construction and launching are comparable with those of making intermediate-range ballistic missiles. However, the U.S.A.F. "Bomark", with a range of about 300 mi., is probably now in production. [The improved Army "Nike Hercules" and "Redstone" have about this range.]

"Antis" is the American name for missiles which may prove effective against ballistic offensive weapons. To knock down one of these is more difficult than to destroy a conventional artillery shell in flight. Missiles with hydrogen warheads may be able to destroy hostile ballistic missiles at heights of 100 mi. or so. Effective defensive weapons of this kind present difficulties of a larger order of magnitude from those of the ICBM and are bound to take a decade longer to solve.

Ballistic Missile Construction

Propulsion – Except for the direct successors of the German V-2 rocket, every missile in service has two separate propulsion systems, the first of which is usually a "booster" rocket to get it off the ground and up to speed.

For the second generation of anti-aircraft and bombardment missiles of intermediate range, the launching rocket must have a power equal to those research rockets which are now being sent up to altitudes of about 100 mi. After the boosters are jettisoned, propulsion will have to be by liquid-fueled motors of the kind now used to sustain the flight of the first generation of anti-aircraft missiles.

The true ICBM will include three stages of rockets, much as in the device for launching the earth satellite.

Steering – Anti-aircraft missiles, even when operating against supersonic aircraft, can use aerodynamic principles for steering. Several American missiles use rudders and elevators mounted in front of the wings.

Ballistic missiles cannot use the atmosphere for steering purposes [when they are up above the atmosphere]. Here again American practice is apparently most advanced: Two of the rocket stages in the satellite vehicles are to have motors whose exit throttles can be swivelled so as to turn it in one direction or another by side thrust.

Aerodynamic heating is the most immediate obstacle to really fast anti-aircraft missiles (up to 3000 mi. per hr.) Heat acquired during passage through the atmosphere is already a problem of some difficulty. Really high-speed aircraft will have to be built of steel. At the much higher speeds of missiles, vaporization of their fuel will probably be used to cool the surface, even though their flight may last for only a few minutes. As far as is known, satisfactory ways of doing this have not yet been developed.

Such problems are most acute in the ICBM, particularly while they fall back to their target on earth. (Small meteors are completely vaporized at heights from 60 to 100 mi.) They will have to be slowed down by equipping the final stage with backward-pointing rockets coming into action about 200 mi. above the earth. The snag here is that the weight of the original missile would have to be far greater than now hoped. Maybe the atmosphere 200 mi. up may be sufficiently dense for ICBM's to be slowed down by some aerodynamic means before they reach the comparatively dense atmosphere.

Guidance – A ground control radar system must carry any anti-aircraft missile sufficiently close to its target for its own detection and for homing devices to come into operation and carry it to a successful interception. The U.K. and the U.S. have such systems, but nothing has been divulged as to their accuracy.

Ballistic missiles cannot be ground-controlled for more than the initial phase to correct any launching errors. Two self-contained guidance systems appear practicable.

The more practicable of these, the "inertial" system, depends on the fact that position of a vehicle can be calculated from its accelerations during its flight. Instruments to do this called accelerometers have been developed in the U.K. and the U.S. for monitoring test missiles of all kinds. However any errors are cumulative, so a wide miss on target would result from small (and inevitable) instrumental errors.

The alternative system is navigation, wherein an optical instrument would continuously observe the position of some star and work out a proper course from this information. The difficulty here is that the optical system would be both complicated and of an accuracy hardly bettered by some of the world's largest telescopes.

A combination of both systems of guidance is being tried out in the American "Snark", one of which recently went astray over Brazil.

Mechanical Properties Versus Microstructure

*By J. B. MALERICH and G. V. CASH**

Tempered martensite is the best microstructure for low-alloy Cr-Mo-V steel if impact strength and ductility (in tensile and stress-rupture tests) are desired; fine bainite is best if short-time tensile and stress-rupture strength is desired; coarse bainite has best creep strength at 900 and 1000° F. (N8m, N8p, Q27a, Q3m, Q6n; AY, *Cr*, *Mo*, *V*)

ONE OF THE IMPORTANT metals we have long used for steam and gas turbine parts is a low-alloy Cr-Mo-V steel made according to General Electric's specification B 5 F 5. Many years of experience with such turbines operating at temperatures below 1000° F. has convinced us that success requires metal with correct microstructure. Some forged rotors are so large that quenching rates cannot be high enough to cause all the austenite to transform into martensite as would be desirable; the slower cooling forms a mixed martensite-bainite structure of limited ductility.

In order to determine the relationships between the microstructure and strength properties of this useful steel at room and elevated temperatures, a study was undertaken of which this article is an outline. The aim was to compare the three significantly different microstructural forms of a single steel, namely, tempered martensite, coarse bainite, and fine bainite; all at hardness of Rockwell C-33 – which would be the correct condition for use in a rotor forging at the compressor end. These three microstructures are shown in Fig. 1.

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Material Tested – Two heats of steel were used in the form of hot rolled, machine straightened and stress-relieved bar stock. Heat A was in ¾-in. rounds and was used for creep testing; Heat B was in ½-in. rounds and was used for the other experiments. Chemical analyses were within specified limits, and as follows (where figures for Heat A are given first): 0.48/0.47 C, 0.47/0.58 Mn, 0.01/0.02 P, 0.013/0.028 S, 0.33/0.30 Si, 1.09/0.87 Cr, 0.12/0.15 Ni, 0.48/0.50 Mo, 0.34/0.28 V, 0.13/0.12 Cu.

All bars were given an austenitizing treatment at 1750° F. for 1 hr. and air cooled prior to immersion in the transformation medium. The programs from then on are as follows:

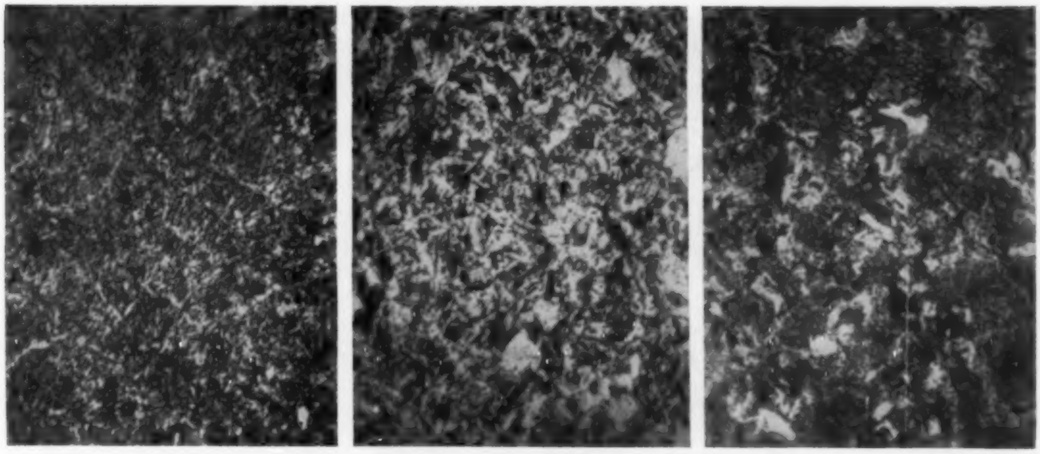


Fig. 1 – The Three Microstructures of Cr-Mo-V Forging Steel Which Were Tested, Namely, Tempered Martensite, Coarse Bainite and Fine Bainite. Magnification 500 diameters

comparative specimens were broken at a known temperature by selecting the appropriate time interval between soaking medium and impact test.

Sub-size specimens, 0.3125 in. square, were used for the test. The notch was ground into the specimen.

	Tempered Martensite	Coarse Bainite	Fine Bainite
Quenching medium	Cool oil	Salt at 850° F.	Salt at 650° F.
Time	↓	3 hr.	30 min.
Final quench		cool oil	cool oil
Resulting hardness	C-57	C-39	C-39
Tempering temperatures	1275° F.	1275° F.	1275° F.
Time for ¾-in. rods	4 hr.	40 min.	40 min.
Time for ½-in. rods	4 hr.	47 min.	1 hr.
Final hardness	C-32	C-33	C-33

Comparing the structures shown in Fig. 1 indicates that:

1. The prior austenitic grain size is the same in all three – No. 7 to 8 and finer.

2. The sub-grain structure (hereafter called "ferritic") is larger in the bainite transformed at 650° F. than in bainite transformed at 850° F. – that is to say, the bainite "feathers" are *larger*.

3. In contrast, the bainitic "feathers" are *coarser* within the higher transformation temperature.

4. Both bainitics display a small amount of martensite – 3 to 5% by volume.

It is the difference in ferritic grain size, plus the variation in feather texture that probably accounts for the variations in physical properties which were observed.

Impact Strength – First the rate of temperature change in the specimen was determined by a thermocouple junction peened into a hole at the center of a dummy test piece. Time-temperature curves were drawn after the specimen was removed from the muffle furnace at 400° F. (or the dry ice and acetone refrigerant) and placed on the testing machine's anvil. Thus, all

Conclusive superiority of tempered martensite is shown in Fig. 2. Not only is the transition temperature 150 to 175° lower than either of the bainitics (white lines), but also the toughness (black lines) at 100 to 400° testing temperature. The coarse bainite structure is more brittle than the fine bainite, as would be expected, and has a higher transition temperature. The transition temperature, by the way, when noted by estimating the proportion of ductile or fibrous fracture in the broken surface, is 30 to 60° higher than the steep part of the curves representing energy absorbed.

Notice that the specimens used were V-notch Charpy measuring 0.3125 in. on a side. The standard size specimen (0.394 in. on a side) absorbed 79 to 82 ft-lb. energy at room temperature, when in the tempered martensitic condition (versus 26 ft-lb. for the sub-size specimens of Fig. 2).

Short-time tensile strength (average of two tests for each condition) is shown in Table I. Specimens broken at room temperature establish the superiority of fine bainite in strength. Paradoxically, the ductility of the fine bainite is at

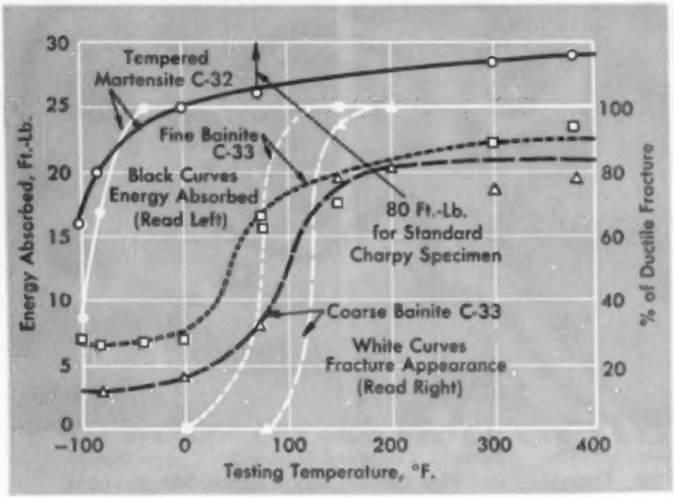
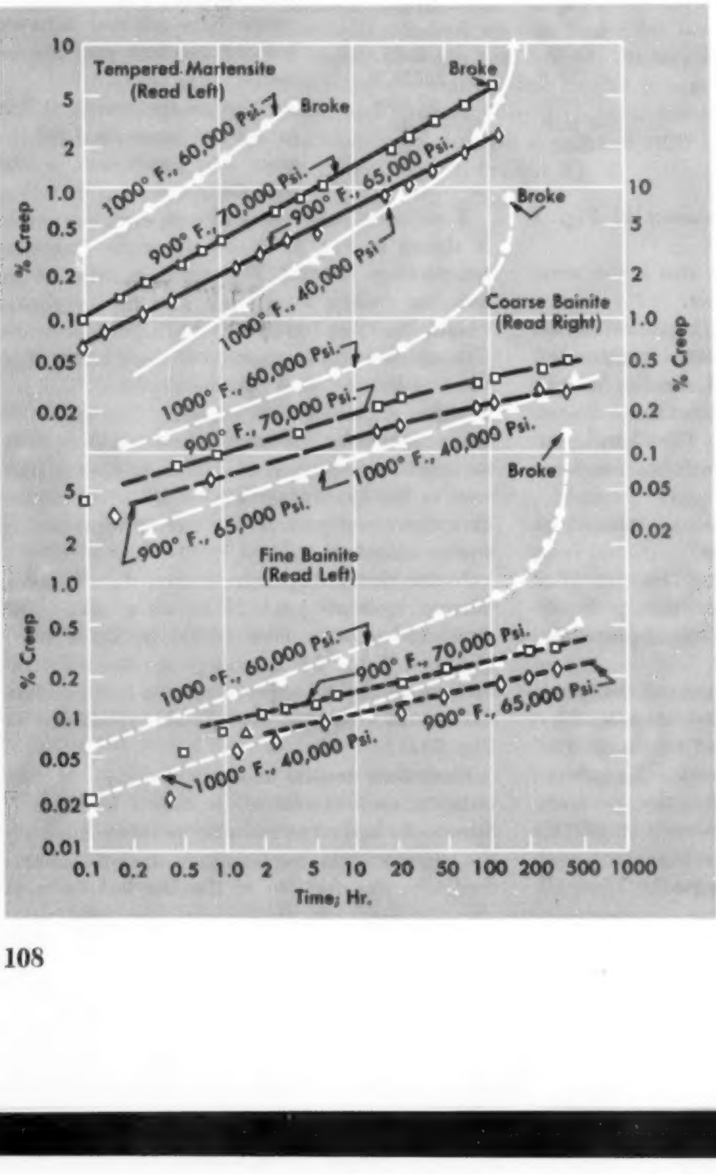


Fig. 2 – Impact Energy (Black Lines) and Fracture Appearance (White Lines) Versus Temperatures for the Three Microstructures. Sub-size Charpy specimens

Fig. 3 – Creep Curves for Cr-Mo-V Forging Steel in Three Microstructural Conditions, All C-32 Hard



about the same level at 75° F., even though it is 20,000 psi. stronger. Coarse bainite is third in both strength and ductility.

Bainites are somewhat stronger at 900 and 1000° F. than tempered martensite. There is no significant difference in the ultimate strengths of the two varieties of bainites at either 900 or the 1000° F. testing temperature, but the fine variety does have slightly increased yield strength at 1000° F. – 5,000 to 7,500 psi. higher than the coarse bainite.

Ductility at elevated temperature, as measured by elongation and reduction of area, is on the same level for the three microstructures. All fractures were transgranular in mode. Thus, these short-time tensile tests were made below the equicohesive temperature of the alloy.

The optimum condition of this Cr-Mo-V forging steel, as far as tensile properties are concerned and as shown in these tests, is the bainitic structure. This combines strength and ductility at all temperatures tested. Fine bainite is to be preferred for slight additional strength and appreciably higher ductility.

Creep Strength – Single-station machines were used with strain measured through a linear differential transformer attached to the gage length. The superior resistance to creep of the bainite is evident from the curves of Fig. 3.

Stresses of 60,000 psi. were so high that second-stage creep (constant strain rate) at 1000° F. is not discernible in any of the structures, nor even at 70,000 psi. and 900° F. for tempered martensite. Thus, it is difficult to compare the creep strength of the bainites under these conditions. The fine bainite seems to be the stronger in first-stage creep.

Creep rates for the bainites in the second stage of creep (between 100 and 500 hr.) are as follows, the parameter being plastic extension, in. per in.:

Stress	Temperature	Coarse Bainite	Fine Bainite
70,000	900	0.00120	0.00115
65,000	900	0.00045	0.00070
40,000	1000	0.00151	0.00280

These figures show that the coarse variety is stronger in second-stage creep.

Stress-rupture tests were run in multiple station machines wherein heat was evenly distributed by forced convection. Tests were run at 900 and 1000° F. Results are summarized in Table II. It will be seen that the bainites are superior in rupture strength when smooth test pieces are used. Notice that all of the fractures in the tempered martensite were transcrystalline, indicating that this structure had not reached its recrystallization (equicohesive) temperature at 1000° F. Nevertheless the mode of failure in the bainites was dependent on stress (stain rate); the higher the stress, the more the tendency for transcrystalline fracture.

Notch ductility is evident in tempered martensite at 900 to 1000° F. Increased sensitivity to the presence of notches is shown in the bainites. In fact, the life of notched specimens of coarse bainitic microstructure is less than that of smooth specimens at 1000° F. and 70,000 psi., yet this same structure is notch

Table I – Short-Time Tensile Tests
(Average Results From Two 0.25-In. Test Pieces)

Property	Tempered Martensite	Coarse Bainite	Fine Bainite
Tested at 75° F.			
Ultimate strength	145,000	151,000	164,000
0.2% yield	138,000	134,000	148,000
0.02% yield	134,000	131,000	147,000
Reduction of area	58.6	51.2	58.6
Elongation	17.0	16.0	18.6
Tested at 900° F.			
Ultimate strength	100,500	113,000	113,500
0.2% yield	85,500	96,500	99,500
0.02% yield	67,000	79,000	82,000
Reduction of area	73.2	73.0	76.7
Elongation	22.5	21.0	21.5
Tested at 1000° F.			
Ultimate strength	93,000	103,500	102,000
0.2% yield	74,500	85,500	93,000
0.02% yield	64,000	74,500	79,500
Reduction of area	77.7	75.0	78.3
Elongation	23.0	19.5	22.6

Table II – Stress-Rupture Tests of Steel, C-32 Hard

Temp.	Stress	Bar*	Time to Fracture	Kind of Fracture†	Elongation	Reduction of Area
Tempered Martensite						
1000	80,000	S	0.4	T	24	77
1000	70,000	N	234			
1000	70,000	S	5.4	T	30	77
1000	60,000	S	4.0 *(a)*	T	3½	
900	80,000	S	27.0	T	20	73
900	80,000	N	150	None		
900	85,000	N	278	None		
900	88,000	N	551	None		
900	70,000	S	135 *(a)*	T	5.0	
Coarse Bainite						
1000	80,000	S	11.2	T	13	62
1000	70,000	N	122.8			
1000	70,000	S	144.1	I	4.0	17
1000	60,000	S	160.0 *(a)*	I	7.0	
900	80,000	S	671.4	I		
900	85,000	S	279.0	I		
900	88,000	S	113	I	12	7
900	80,000	N	1655	None		
900	85,000	N	279	None		
900	88,000	N	552			
Fine Bainite						
1000	80,000	S	39.6	T	13	51
1000	70,000	N	25.5			
1000	70,000	S	138	I	13	20
1000	60,000	S	400 *(a)*	I	11	
900	80,000	S	150	None		
900	85,000	S	278	None		
900	88,000	S	552			
900	80,000	N	150	None		
900	85,000	N	278	None		
900	88,000	N	551			

*S is smooth; N is notched. *(a)* Data from creep test, Fig. 3.
†T is transcrystalline; I is intercrystalline.

Table III – Summary of Mechanical Properties of Cr-Mo-V Forging Steel as They Vary With Microstructure

Property	Tempered Martensite (T.M.)	Coarse Bainite (C.S.)	Fine Bainite (F.B.)
Impact strength	Best Transition temperature (T.T.) –100° F. Energy absorbed in fracture at least 40% higher than the bainites at any temperature	Worst T.T. +125° F.	Fair T.T. +75° F.
Short-time tensile strength at 75, 900 and 1000° F.	Worst	Fair Yield and ultimate 10% lower than F.B. at 75° F.; 5% lower at 900 and 1000° F.	Best Yield and ultimate 10 to 15% higher than T.M.
Short-time tensile ductility at 75, 900 and 1000° F.	Best Elong. and R.A. 10 to 15% higher than C.B. at 75° F., 5 to 10% higher at 900 and 1000° F.	Worst	Fair Elong. and R.A. about 5% lower than T.M. at all temperatures.
Creep strength at 900 and 1000° F.	Worst	Best Slower second-stage creep rate than F.B.	Best
Stress-rupture strength at 900 and 1000° F.	Worst	Fair	Best 100 hr. better than T.M. at 1000° F. and 70,000 psi.
Stress-rupture ductility at 900 and 1000° F.	Best All fractures transcrystalline	Worst May be notch brittle at 1000° F.	Fair Elong. and R.A. 30 to 40% lower than T. M.
Microstructural stability	Best Recystallization temperature above 1000° F. at 135 hr.	Worst Can recrystallize after 144 hr. at 1000° F.	Worst Can recrystallize after 138 hr. at 1000° F.

ductile at 900° F. Fine bainite has longer stress-rupture life than coarse bainite has whether the fracture be transcrystalline or intercrystalline. Thus, the fracture strength of fine bainite may be dependent on the texture within the ferritic grains, while that of coarse bainite is influenced in part by the size of the ferritic grains.

Again, the superior ductility of tempered martensite is apparent. Fine bainite is more ductile than the coarse variety. Apparently, time at tempering temperatures forms an embrittling microconstituent at the ferritic grain boundaries in the 850° F. bainite (coarse). This results in *(a)* relatively good second-stage creep rates, *(b)* low ductility at rupture, and *(c)* notch sensitivity at 1000° F.

The data in this paper may be summarized as in Table III, which shows that the mechanical properties of the Cr-Mo-V forging steel are markedly affected by microstructure (when heat treated to equal hardness, C-32).

Many of the property differences shown in these comparative tests can be attributed to sub-grain structure, since all three varieties had the same austenitic grain size. Tempered martensite represents the closest knit sub-grain. This is shown by the toughness in impact tests and in the tensile ductility at all temperatures. Because all fractures in martensite were transgranular, we cannot compare strength and ductility of the three variations above the recrystallization or equicohesive temperature. It can be said that tempered martensite is the most stable structure of this steel, at the hardness of our samples, C-32, because the fracture was transgranular in the stress-rupture tests at 1000° F., regardless of strain rate. On the other hand, at low strain rates, when recrystallization had time to progress, the bainites broke around the grain.

Because all the bainitic tensile bars (short-time tests; rapid strain rates) broke transgranularly, it is important to note in Fig. 1 the larger size of the ferritic "needles" or "feathers", and the closer knit structure within these sub-grains shown in the fine bainite transformed at 650° F. The result is increased ductility and toughness. Yet, fine bainite is superior to coarse in short-time tensile and stress-rupture tests. In short-time tensile tests, impact tests, and those stress-rupture tests which resulted in transcrystalline

failure, the texture within the ferritic grains – that is, coarseness within the bainitic needles – helps the strength-ductility levels of the bainites. The finer the texture, the higher are the toughness, strength *and* ductility as measured by tensile yield point and stress-rupture tests. In these respects fine bainite is better than coarse.

When fracture is intercrystalline the ferritic grain size – that is, the bainitic "needles" – determine the strength-ductility levels. The larger the grains, the less the grain boundaries, the higher the rupture strength *and* ductility.

The relatively poor ductility of the samples of coarse bainite which broke in intercrystalline fracture – that is to say, having notch brittleness at 1000° F. – indicates that there is a slow embrittling reaction or precipitation at 1000° F. which stiffens the ferritic grain boundaries.

From the comparative microstructures in Fig. 1, it is obvious that the nucleation and growth rates at 650° F. provide few ferritic nuclei which are able to grow rapidly. Thus, large ferritic grains appear with a close-knit substructure. The opposite condition exists at 850° F.; here the nucleation rate is fast and the growth slow.

Because of the marked difference in impact transition temperature between the three structures (Fig. 2), it appears that toughness is the property most greatly affected by change in heat treatment. In fact, it is a reasonable supposition that the proportion of bainite present in normalized B 5 F 5 steel can be calculated from the transition temperature.

Because all of the test bars were equal in hardness within a range of plus or minus one point on the Rockwell C-scale, it might be expected that the short-time tensile yield points would be constant, particularly at room temperature. Table I shows that this supposition is unfounded; at constant hardness the yield strength is a function of microstructure (grain size, texture, and phases present). Notice that the spread between yield and ultimate stresses of the fine bainite structure (16,000 psi.) is greater than that of the tempered martensite (7000 psi.) – a structure with low yield but good ductility. It is obvious that the fine bainite possesses the optimum conditions – a high yield point and good ductility.

Creep strength of tempered martensite is comparatively poor, since the first-stage plastic extension rate is rapid. This is probably due to a sluggish rate of work hardening. Again, the recrystallization rate of tempered martensite in our creep tests does not appear to be rapid since all fractures were transgranular. This ability to flow in creep is also shown in the ductility of notched specimens.

The bainites have slower creep rates, but the limiting property here would seem to be the ductility. Ductility figures are optimum at the slow strain rates, but where ability to flow without breaking becomes important (such as in a notched high-temperature application) the bainites – especially the coarse type – may not be the best condition for the steel.

Probabilities in Fatigue Testing

*By F. E. RICHART**

At the risk of adding a little more confusion to the art of testing materials, it seems well to analyze by statistical theory the variations which are apparent in any series of fatigue tests. This might be superfluous to anyone who has studied the recent technical literature. This would make it obvious that many fatigue results are about as reliable as impact tests – another test highly sensitive to notches and defects of all degrees of severity.

Many designers, I fear, have adopted the theoretical basis of most of the common formulas found in textbooks on mechanics, and are prone to think of metals as isotropic materials and love to manipulate the formulas based on this assump-

*University of Florida, Gainesville, Fla. A short version of a talk before the 1957 Southern Metals Conference, Jacksonville, Fla.

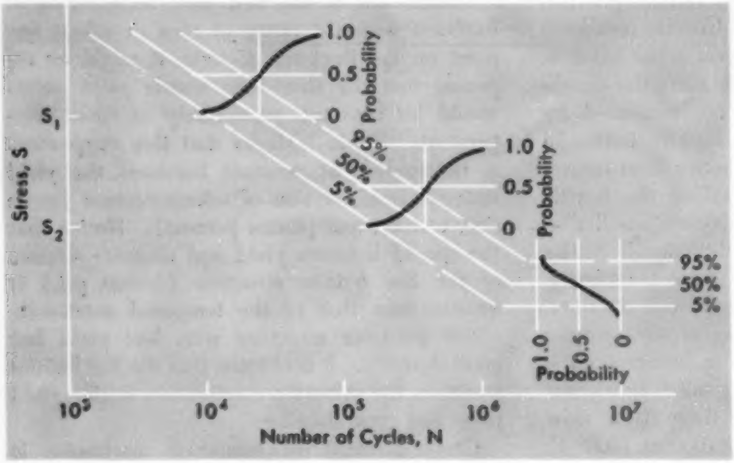


Diagram Illustrating the Probability of Failure of Samples Tested in Fatigue by Conventional Means

tion. With the known variables in surface finish, microstructure, notches, pits, internal flaws, corrosion, cold work, chemical segregation, testing machines and test routines – all having a pronounced effect on the performance of any given test piece – it is no wonder that ten fatigue specimens, cut from the same bar of metal, at the same stress level, will show a wide scatter of number of cycles to failure, since failure usually starts at and progresses from some discontinuity at or near the surface. The scatter has been reported to be of the order of plus or minus 10% of the average value of stress. Last year an English paper on testing machines reported a variation of 3 to 4% in results from testing machines of the same type when apparently testing identical (?) test pieces.

If a relatively large number of specimens are stressed between a particular minimum and maximum stress value, and the number of specimens counted that fail at each particular number of cycles, a diagram is obtained which illustrates the *frequency* of failure at each number of cycles. This is shown in the diagram by the S-shaped curves at the two stress levels. These curves indicate the probability of failure at each particular number of cycles. Thus, for the given stress, S_1, a low probability of failure exists at a low number of load cycles, and the probability of failure increases with increasing number of cycles until a number is reached for which the probability is 1.0. At such a point there is a 100% probability that the specimen will have broken before this number of stress cycles.

In a similar manner, we can estimate the probability of failure of specimens at some number of cycles, say 10^7. As the stress is increased there exists a higher probability that the specimen will fail before sustaining 10^7 cycles. A curve representing the probability of failure at 10^7 cycles is also shown on the figure.

By connecting points on the diagram which represent the same probability of failure, we may establish a series of curves defining the S-N relations for equal probabilities of failure. As a result, a new parameter is introduced and it is no longer proper to talk of "the S-N curve", but rather it is necessary to specify the "S-N-P relations" where S stands for stress, N stands for number of alterations and P stands for probability of failure. Dotted lines are shown on our diagram connecting the 5%, 50% and 95% probability of failure superposed on the conventional S-N relations.

The line representing 50% probability of failure corresponds to the average value customarily assigned the name of "the S-N curve" for a particular material and testing condition. This "S-N curve" has been used by designers by applying a suitable factor of safety (ignorance?) whereupon they use the reduced stress without further concern as to the actual life of the part.

The tests required to give the basic S-N-P information for a given amplitude of load cycles involve determinations of endurance life and endurance limit. For endurance life, at least 20 and preferable 50 to 100 specimens must be tested at each of several stress levels. From the distribution of these numerous test results the corresponding probabilities of surviving each particular number of cycles can be established. Diagrams may then be drawn, if desired, which illustrate the S-N relations for different probabilities of survival.

Correspondence . . .

Cathodic Etching of High-Purity Aluminum

OTTAWA, ONT.

An effective cathodic etching method for high-purity aluminum was developed at the Mines Branch, Ottawa, in 1956, during an investigation on the corrosion of aluminum and its alloys in distilled water. The sample is made the cathode in a cell (Fig. 1), with distilled water at 100° C. (212° F.) as the electrolyte.

Graphite is used as the anode. It is put in a porous container such as alundum to prevent contamination of the electrolyte. Direct current of at least 100 v. is required, to give a current density of 1 milliamp. per sq.cm. Current is applied for 5 to 30 min.; etching of the grain boundaries makes the grains readily visible.

A film usually forms on the sample, especially during the longer etching times. It can be removed by defilming in a boiling solution of 20 g. chromic acid and 35 cc. phosphoric acid made up to one liter with distilled water.

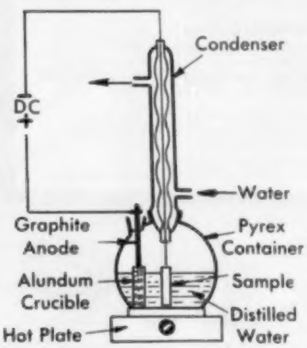


Fig. 1 – Cathodic Etching Cell

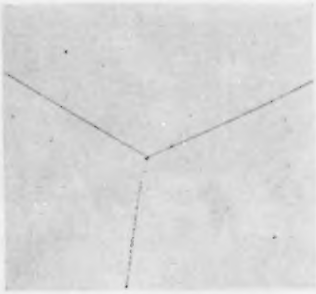


Fig. 2 – Grain Boundaries in High-Purity Aluminum, Electropolished and Cathodically Etched 15 Min. 250 ×

Figure 2 shows a sample of high-purity aluminum (0.0068% Si, 0.0028% Fe, less than 0.002% Cu, remainder Al) after etching 15 min. The sample was prepared by mechanical polishing to a 4/0 emery paper, then electropolishing in 20% perchloric acid in ethyl alcohol (De Sy-Haemus' electrolyte).

This cathodic etching method is also effective in bringing out the grain of high-purity aluminum in the unpolished condition. Considerably longer etching time is necessary.

C. F. DIXON
Metallurgist
Nuclear Metallurgy Section
Department of Mines and Technical Surveys

M. J. LAVIGNE
Research Metallurgist
Atomic Energy Div.
Canadian Westinghouse Co., Ltd.

Machines for Literature Searching

WASHINGTON, D.C.

The article in the February issue of *Metal Progress* on "Machine Searching of Metallurgical Literature" by Allen Kent, Robert E. Booth and J. W. Perry makes some statements which I believe to be misleading. Under the heading "Available Machinery", the statement is made: "Several types of machines can be used to process this type of encoded material . . . These machines can be either specially programmed or specially designed for the searches described." The article mentions specifically the IBM X794, which is not in production, the Eastman Minicard system, which is not yet operational, and the W.R.U. Searching Selector, which is a handmade experimental model and is admittedly a slow-acting device based on electromagnetic relays.

To program an existing machine is one thing; to design and then to build a machine is quite another.

MORTIMER TAUBE
President
Documentation, Inc.

EDITOR'S NOTE: In compressing Mr. Kent's rather long paper into the limited number of pages available in *Metal Progress*, much of the detail concerning the status of machine development had to be omitted. We regret it if the impression was given that machines specifically designed for the A.S.M. searching project are now on the market. In

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Literature Searching . . .

the meantime, the W.R.U. Searching Selector, specifically designed for searching encoded abstracts, is being used for pilot searching experiments. Also general-purpose computers now commercially available can be used although the necessary programming is quite complicated. We believe that by the time the pilot project is completed, two or three years hence, the machine manufacturers will be ready to build the necessary equipment or to adapt present designs to the purpose.

Burns From Atomic Bombs

In the short extract from Gordon Dunning's talk under the above title in *Metal Progress* for April, a regrettable misquotation is contained. The last sentence in the third column, (p. 81) should read:

"At 3.5 miles [from a 20,000 kiloton burst] the effect of total exposure to instantaneous radiation would be unimportant, yet the thermal exposure would be great enough to char completely any exposed skin and to ignite normal clothing, and the blast wave would undoubtedly destroy even reinforced concrete buildings."

3.5 miles is bad enough for a super-bomb without increasing the radius of demolition erroneously to 28 miles as was done in *Metal Progress*. 28 miles is the radius for fatal burns from full exposure to the heat. If you're behind a concrete building 28 miles away at the time you'll be lucky. You won't be burned and the wall probably will not fall on you.

Explosions of Sodium With Water

WEEHAWKEN, N.J.

The "Atomic Age" page, "Troubles With Atomic Submarine 'Seawolf'" in the March issue, p. 92, contained the statement: "Experience has indicated that violent reactions between sodium and water are producible under carefully controlled experimental conditions. Accidental mixing has produced only moderate reactions."

My own experience with sodium

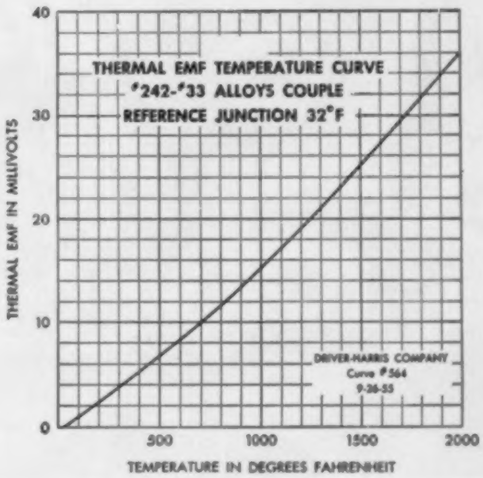
Driver-Harris Announces Major Advance in Pyrometry!

New #242-33 Thermocouple* for Reducing Atmospheres Maintains Calibration Through a Greatly Extended Life

This new Driver-Harris Thermocouple was developed primarily to withstand industrial reducing atmospheres at high temperatures and thereby to end the danger of runaway furnaces and ruined charges.

Unusually high resistance to "green-rot" attack is the outstanding property of the alloys of this thermocouple, whose analysis is:

Positive Leg (No. 242 Alloy)	Negative Leg (No. 33 Alloy)
80/20 Ni-Cr + Cb	3% Si-Ni



Although the thermal-emf response of this thermocouple is lower than the conventional thermocouple now in use, the slope of its temperature-emf curve is virtually parallel in the higher ranges of temperature in which both couples are designed to be used. Thus, the thermal-emf sensitivities are equivalent in the higher temperature ranges.

Tested against the conventional thermocouple in an atmosphere of the following nominal composition: CO...10%; CO_2...5%; CH_4...1%; H_2...16%; O_2...Nil; N_2...Balance (best for accelerating green-rot attack), exposure after 212 hours showed *only +0.13 mv. drift for the D-H thermocouple, and −7.54 mv. for the conventional thermocouple.*

When the thermal-emf of the conventional thermocouple *drops,* as in a reducing atmosphere such as this, the working temperature of the furnace controlled by it *rises.* However, when a #242-33 couple is used under the same conditions the thermal-emf remains substantially constant. This means that a furnace controlled with the new D-H thermocouple* *cannot overheat and ruin charges.*

Members of the Heat-Treating and Instrument Manufacturing Industries are urged to investigate this new Driver-Harris Thermocouple without delay so that through their combined efforts all U. S. Industry can benefit. Complete technical data and application information is waiting for your inquiry. Write today to our Thermocouple Division.

*U. S. Patent No. 2,691,690

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Sodium Explosions . . .

may be of interest in this connection.

After completing some experimental work I had to dispose of a 10-lb. can containing four bricks of sodium metal. We had a frozen river near our plant and it was decided that we would throw the bricks on the ice, which was then 4 to 6 in. thick.

We threw one brick as far out on the ice as we could. It started to sizzle and in a few seconds there was a terrific explosion and flame. The brick went up in the air several hundred feet and when it came down it repeated the performance about six times before it disintegrated.

Each explosion could be heard for miles and drew crowds to the river to see what was happening. The force of the explosion was so great that a hole about 10 ft. in diameter was made in the ice. The whole thing was quite terrifying.

A. J. Marino

Incentives for Workmen and Engineers in Latin America

Santiago, Chile

The letter on "Heat Treatment Operations in Mexico" from Harry B. Osborn, Jr. in the January issue of *Metal Progress*, p. 132, states some facts which are certainly true. However, I would like to comment on some of his conclusions. I have never been in Mexico but I think that basically the problems are the same in all Central and South American countries.

Mr. Osborn's criticism is primarily directed against the workmen, but should not top management take some of the blame? South America is always a sellers' market so why should management worry about improving quality when products sell anyhow? And why worry about cost when salaries are low?

Mr. Osborn tells about a plant where the workmen would not accept an incentive bonus. My guess is that, since this bonus plan was introduced without time study, it may have raised earnings too drastically and then been later

Latin America . . .

dropped or lowered with consequent loss of confidence. Or perhaps it was not adequately explained to the men. It is my firm belief – and also experience – that with a sound incentive policy based on time studies, excellent results will be obtained in Latin American countries.

Mr. Osborn talks about the low salaries of graduate engineers, but this is simply another reflection of the low standard of living. It is also another result of shortsighted management. Such shortsightedness seems not to be confined to Mexico, for I have read complaints on unsatisfactory pay for graduate engineers in the U.S. also. Mr. Osborn's final recommendation to import cheap Mexican engineers is probably facetious and a poor substitute for inciting more American students to choose a technical career by attractive salaries. (See Dr. Chipman's letter, "More Metallurgists for Russia", in the same issue, p. 134.)

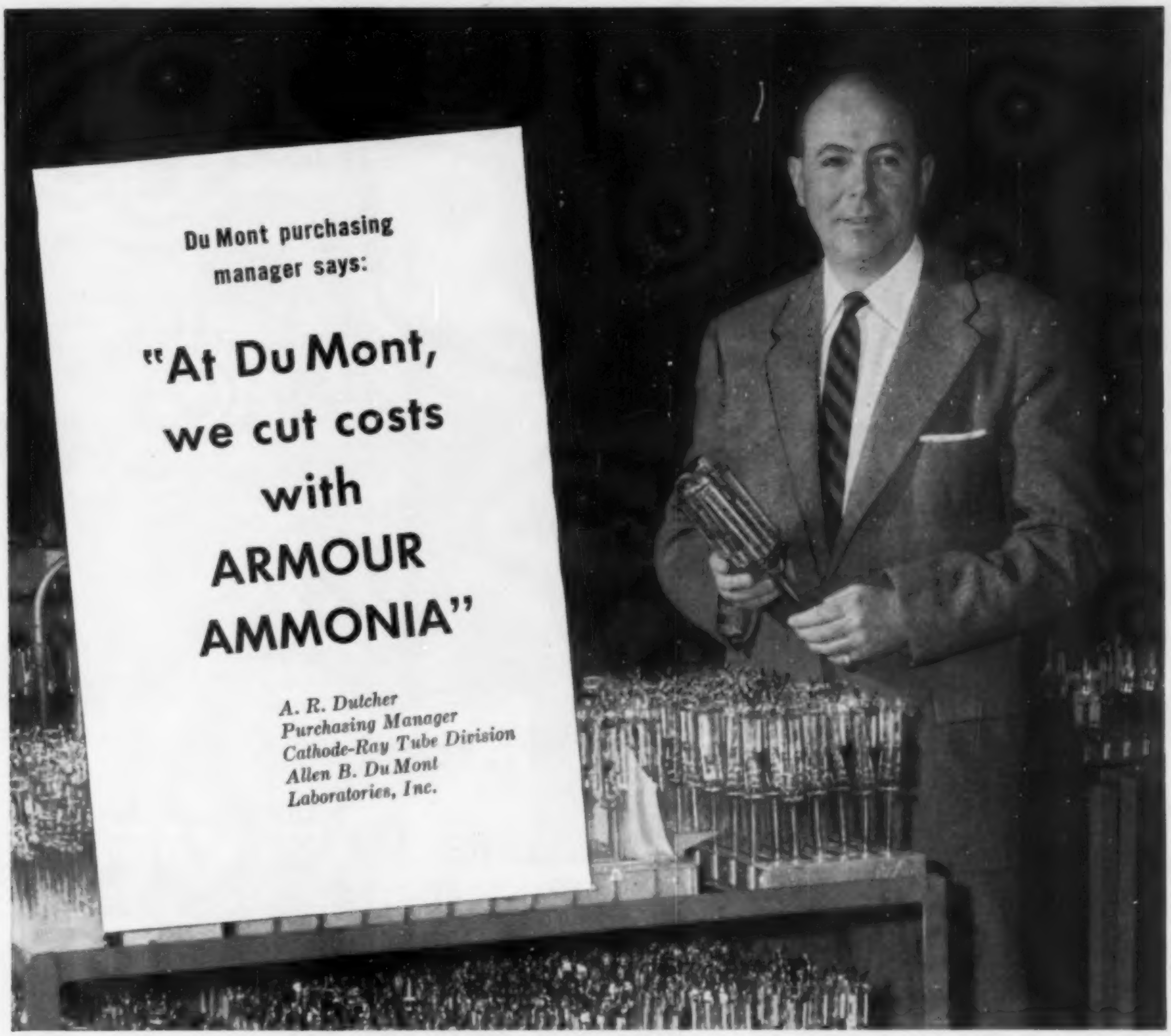
FEDERICO HRUSKA H.
Works Manager
Tube and Sheet Plant
Manufacturas de Cobre S.A.

The "Cry" of Twinning

Paris, France

It has been known for a long time that when a bar of tin is bent a very characteristic sound is heard called the "tin cry". This behavior has served to determine rapidly whether soft brazing wires or bars of solder have a tin or lead base. Lead, which is of cubic crystallinity, does not exhibit this phenomenon which is common for hexagonal cadmium and zinc as well as for tetragonal tin.

Investigations by both E. N. Andrade and Bruce Chalmers have shown that the phenomenon is caused by the formation of mechanical twins which inevitably accompany the deformation of metallic materials which crystallize in other than the cubic system, *if* the crystal lattice dimensions are larger than a certain minimum. This deformation twinning produces a large number of twins in noncubic metals, and they resemble the polysynthetic twins known to mineralogists. In cubic metals these twins form after an an-



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Twinning . . .

neal subsequent to deformation. Examples are alpha brass and nickel-containing austenites.

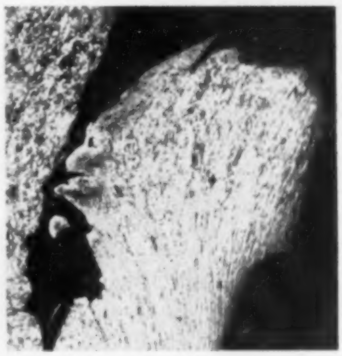
One can agree with Professor Andrade who reasons that the production of sound on mechanical twinning is a general phenomenon and that even when no audible "cry" is perceived, the sound exists nevertheless, but at a frequency far too high to be picked up by the human ear.

It may likewise be theorized that the phenomenon of a "cry" accompanying the formation of martensite from austenite in steels is similar to the effect just described. Forster and Scheil studied the matter by taking a motion picture (with sound effects), which certainly supports the concept of martensite formation as a result of mechanical twinning.

Thus, it is seen that a generic term "cry of twinning" may be given to a group of metallurgical phenomena.

ALBERT M. PORTEVIN
Member of the Institute

Gremlin on the Bay



WASHINGTON, D.C.

Our metallographic work is often plagued by gremlins but seldom does one show himself so clearly as this. It is a burr on a steel part Rockwell C-25 hard, and was formed by rubbing contact with steel of the same hardness. The photomicrograph (1% Nital etch, 200 ×) was made by Irene C. Minor.

W. L. HOLSHOUSER
Metallurgist
National Bureau of Standards

EDITOR'S NOTE: A yachtsman might see an aerial view of a snug little harbor.

Personal Mention

Walter A. Dean

Well-known as an authority on light metal alloys and process developments, WALTER A. DEAN is now assistant development metallurgist for the Aluminum Co. of America at the Pittsburgh plant. His former position in Cleveland as chief metallurgist of the Alcoa works there will be filled by THOMAS R. GAUTHIER, chief metallurgist of Alcoa's forge plant.

As works chief metallurgist in Cleveland, Dr. Dean has had charge of all metallurgical work required for the operation of three divisions – ingot casting, foundry (permanent mold and sand mold), and forge shop – as well as supervising the chemical and metallurgical laboratories. In the new position in Pittsburgh, he will give prime attention to metallurgical developments which will affect operations in the newly consolidated fabrication and castings division of Alcoa.

Dr. Dean began his career with Alcoa at the research laboratories in New Kensington, Pa., in 1929, just after receiving his doctor's degree from Rensselaer Polytechnic Institute. Two years later he moved to Cleveland and in 1944 became assistant manager of the permanent mold plant there. He has been Cleveland works manager since 1949 and, in his new position, will continue to serve as coordinator of titanium fabricating activities for Alcoa.

Walter Dean has been a member of for about 20 years, although his principal activities have centered in the Institute of Metals Div. of the American Institute of Mining, Metallurgical, and Petroleum Engineers. He was chairman of this division in 1952, and currently is a vice-president and member of the board of directors of the Institute.

Earl E. Swanson was transferred and promoted from product engineer at the Roller Chain Div., Chain Belt Co., to administrative assistant to the general manager at the General Road Machines Division of the company, Niles, Ohio.

Francis M. Cain, Jr., has accepted the position of manager of metallurgical services with Nuclear Materials & Equipment Corp., Apollo, Pa. He was formerly associated with the atomic power division of Westinghouse Electric Corp., Pittsburgh.

John A. Howell is sales metallurgist in charge of the new Los Angeles sales office of Rolled Alloys, Inc., Detroit. During the past five years, Mr. Howell has been connected with the industrial furnace department of Westinghouse Electric Corp., in Meadville, Pa.

Arnold L. Rustay was chosen to fill the newly created position of technical director as part of the expansion program of the research and development department of the Wyman-Gordon Co.'s eastern division in North Grafton and Worcester, Mass. Mr. Rustay has been with Wyman-Gordon for nearly 20 years and last held the position of director of research. Other promotions in the expansion program include the appointment of **Chester J. Orciuch** as metallurgical manager with responsibility for the Worcester and North Grafton laboratories, and the promotion of **Carl G. Bergstrom** to chief metallurgist at the Worcester plant.

James W. Faber has returned to Westinghouse Electric Corp. after release from active duty in the U.S. Army. He is now an associate engineer in the materials application and development section, metallurgy division, Westinghouse Aviation Gas Turbine Div., Kansas City, Mo.

Howard E. Boyer

A new editor, HOWARD E. BOYER, has been added to the publications staff of the American Society for Metals, as managing editor of the Metals Handbook.

Mr. Boyer comes to after 18 years as chief metallurgist with the American Bosch Div. of the American Bosch Arma Corp. in Springfield, Mass. When he joined the company, he was a metallurgist without a department, but in the 18 succeeding years he not only organized the materials engineering department, but developed one of the finest materials laboratories in the East. He received his engineering education at the Ohio State University.

For many years, Mr. Boyer has been active in several technical societies, including A.S.T.E. and A.S.T.M. He has been on the speaker's list for both A.S.T.M. and A.S.M., and has served as chairman of the Springfield Chapter and as a member of the National Nominating Committee. He is the author of more than 80 papers and articles on the science and engineering of metals.

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Personals . . .

John T. Bradley ⊕ is now managing the sheet steel porcelain enamel division and the cast iron foundry and porcelain enamel division of P. I. Mfg., Inc., Manila, Philippines.

W. Scott Lightner ⊕ has been added to the metallurgical staff of Vanadian-Alloys Steel Co., Latrobe, Pa., as research engineer. Mr. Lightner, previously stress technologist for the Fairchild Aircraft Div., Fairchild Engine and Airplane Corp., Hagerstown, Md., will be attached to the firm's metallurgical laboratory in Latrobe to work on special project research.

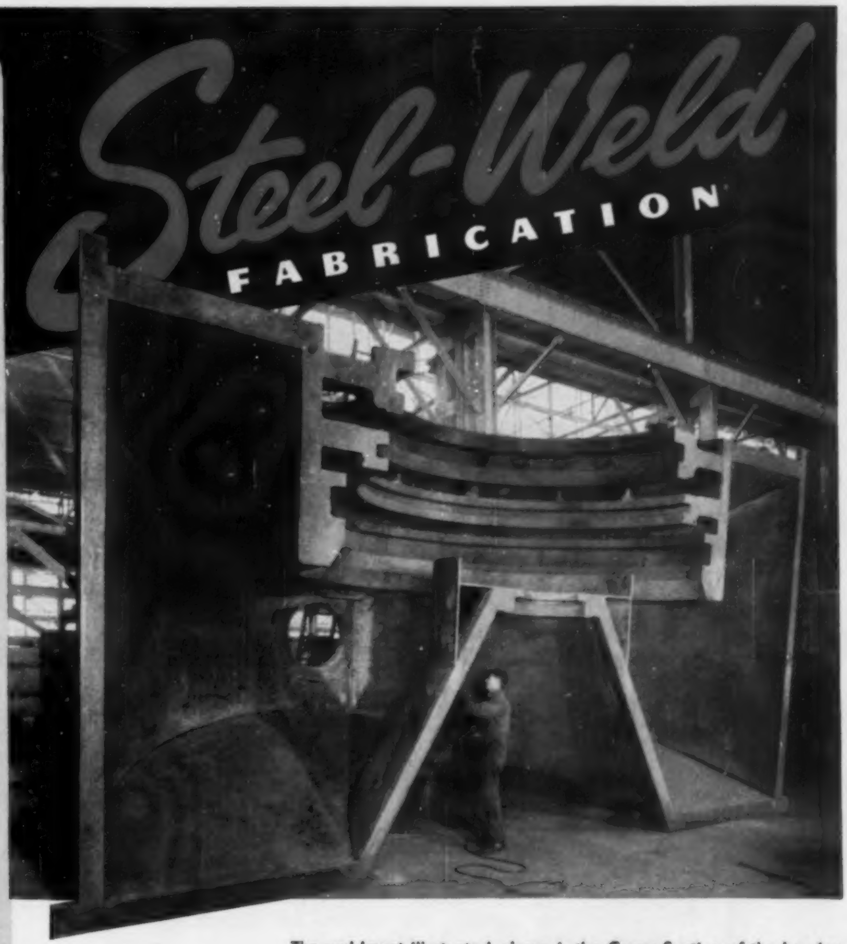
John P. Clark, Jr., ⊕ and **Edward R. Talone** have been appointed representatives of the Alloy Engineering Co., Berea, Ohio, for the eastern Pennsylvania, Maryland and Virginia region. They are both affiliated with the John P. Clark Co. of Philadelphia.

Raymond A. Quadt ⊕ has been assigned the post of director of research and development for the Bridgeport Brass Co., Bridgeport, Conn. Mr. Quadt will continue as a vice-president of research and development of the Hunter Douglas Aluminum Corp., Riverside, Calif., which was acquired by Bridgeport Brass last year.

L. J. Weber ⊕ has been named manager of product development for the Aluminum Cooking Utensil Co., Inc., New Kensington, Pa., a subsidiary of the Aluminum Co. of America. Formerly manager of Alcoa's cooking utensil manufacturing division, Dr. Weber's work in this newly created department will be coordinated with various sales divisions of Aluminum Cooking Utensil Co., and Alcoa. He came to Alcoa in 1927 as a metallurgist in the research laboratories and transferred to the Aluminum Cooking Utensil Div. in 1931.

Shadburn Marshall ⊕ has been appointed director of metallurgical research at the Central Research Laboratories of Air Reduction Co., Inc., Murray Hill, N. J. Prior to joining Airco, Dr. Marshall specialized in materials application and process development for the fabrication of metals, working with nuclear materials and fuel elements.

Steel-Weld FABRICATION



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The weldment illustrated above is the Cover Section of the housing for a 300,000 kw Steam Turbine . . . it weighs 55 tons. This unit and those shown at the left are typical of the thousands of Steel-Weld Fabricated parts and assemblies produced by Mahon each year for manufacturers of processing machinery, machine tools, and other types of heavy mechanical equipment. Are you taking full advantage of the economies offered by welded steel components in your products? In the design of almost any type of heavy machinery, or mechanical engineering project, there are parts and sub-assemblies that can be produced more economically and more satisfactorily in welded steel . . . because, in weldments you save time and pattern costs, and you get greater strength with less weight, plus the additional advantages of greater rigidity and 100% predictability. When you consider weldments, you will want to discuss your requirements with Mahon engineers, because, in the Mahon organization you will find a unique source for weldments or welded steel in any form . . . a fully responsible source with complete facilities for design engineering, fabricating, machining and assembling . . . a source where design skill is backed-up by craftsmanship which assures you a finer appearing product embodying every advantage of Steel-Weld Fabrication. See Sweet's Product Design File for information or have a Mahon sales engineer call at your convenience.

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Personals . . .

David V. Ragone, assistant professor of metallurgical engineering at the University of Michigan, was chosen to receive the Engineering Society of Detroit's 1957 award as "an outstanding young engineer". A 1951 graduate of Massachusetts Institute of Technology, Professor Ragone was cited by ESD for his activities as a teacher, researcher and administrator. In addition to teaching courses at the University, he has had administrative responsibility for his department's Sohma Precision Laboratory and the Mass Spectrographic Laboratory, and is conducting research on the thermodynamics of liquid metals.

Irving J. Donahue, Jr., has been named vice-president of Carroll Pressed Metal, Inc. A graduate of Worcester Polytechnic Institute and Harvard Graduate School of Business, Mr. Donahue has gained experience in the metal industry as a metallurgist, foreman, superintendent and plant manager.

George R. Beatty, formerly connected with the Beryllium Corp., Reading, Pa., is now a metallurgist for Capitol Products Corp., Mechanicsburg, Pa.

Robert J. Teitel has joined the newly formed nuclear and basic research laboratory of Dow Chemical Co., Midland, Mich., as a physical metallurgist. His former experience in the nuclear reactor field was gained at Brookhaven National Laboratory.

O. Cutler Shepard is now professor of metallurgy and director of the division of metallurgical engineering at Stanford University.

Charles A. Heuer was named chief of Roll Bond technical development for the Western Brass Mills Div. of Olin Mathieson Chemical Corp., East Alton, Ill. Mr. Heuer has held various positions at both the New Haven and East Alton divisions of the company.

John P. McCafferty now represents Universal-Cyclops Steel Corp. and Viking Tool and Steel Co., Inc., in the field of high temperature alloys, stainless steels, toolsteels and rare metals. He was formerly affiliated with Brace-Mueller-Huntley Co.

Personals . . .

J. S. Jordan, an employee at Edgcomb Steel Co. for 16 years, is now office manager.

Thomas P. May has been selected as manager of the International Nickel Co. Kure Beach-Harbor Island Testing Station on the North Carolina coast, where research is conducted on the behavior of materials in salt water and sea air. Dr. May has served as technical manager of the station since 1954, with headquarters in New York. His new position combines both technical and operational management of the station. After serving for eight years as head of the corrosion section of the chemistry division, U.S. Naval Research Laboratory, Washington, D.C., he joined the corrosion engineering section of Inco's development and research division in 1947.

Albert G. Haynes has accepted a position as plant engineer with Culligan, Inc., Northbrook, Ill. Mr. Haynes was previously affiliated with Oscar C. Rixon Co., Franklin Park, Ill., as director of research and development.

K. P. O'Kelly is currently holding the position of project engineer, structures materials, for Chance Vought Aircraft, Inc., Dallas, Tex.

Albert J. McConnell has been given the assignment of assistant branch manager for the Baltimore sales branch of Crucible Steel Co. of America, Pittsburgh. Mr. McConnell joined the Baltimore office as a sales service engineer in 1949 and was transferred five years later to Philadelphia in a similar capacity, holding this post until his present appointment.

A. F. Sprankle has resigned as director of metallurgy and assistant to the president of Northeastern Steel Corp., Bridgeport, Conn., to become director and assistant vice-president of Vanadium Corp. of America, New York.

Laynez Ackermann has left his post as research analyst at the Menasco Mfg. Co., Burbank, Calif., to become a senior engineer in the high reliability section of the Inland Testing Div. laboratories, Cook Electric Co., Chicago.

Personals . . .

William P. Roe is now associated with the central research laboratory of American Smelting & Refining Co., South Plainfield, N. J. Prior to this appointment, Mr. Roe was head of the physical metallurgy section of the Southern Research Institute, Birmingham, Ala.

Denis L. Ramball has accepted a job as chief metallurgist for the Billings & Spencer Co., Hartford, Conn. He was previously affiliated with the Sanderson-Halcolm Div. of Crucible Steel Co., Syracuse, N. Y.

Robert W. Miller has assumed new responsibility as headquarters induction heating sales specialist for the industrial heating department of General Electric Co., Shelbyville, Ind. Mr. Miller was a member of the sales department of the Induction Heating Corp., New York, and a consultant to the Cincinnati Milling Machine Co. prior to joining General Electric.

B. R. Queneau, chief metallurgist at the Duquesne (Pa.) Works of U. S. Steel Corp., has been transferred as assistant manager, metallurgy, inspection and research, to the Tennessee Coal & Iron Div., U. S. Steel Corp., Fairfield, Ala.

Francis J. Shortsleeve has been named assistant director of research of the Metals Research Laboratories, Electro Metallurgical Co., a division of Union Carbide Corp., Niagara Falls, N. Y. Dr. Shortsleeve began his career with Electromet as an assistant research engineer at the Metals Research Laboratories in 1953, and a year later was promoted to assistant group manager of the metals research group. He was made group manager of this group in 1955.

R. A. Schoenfeld has been elected executive vice-president of Lindberg Industrial Corp., Chicago. Mr. Schoenfeld has been engaged for the past year in re-organizing the company's Cleveland operation and has completed an assignment as administrative assistant with Lindberg Engineering Corp. The Cleveland office will remain as Mr. Schoenfeld's administrative responsibility along with his work as executive vice-president of Lindberg Industrial Corp.

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turning

On B-1113 stock, cast alloy gave 500 pieces per grind. *Vasco Supreme* delivers 3500-4000 pieces—upping production 20%.

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Cast iron cams. Standard high speed steel formerly used gave 7 cams per grind—*Vasco Supreme* now cuts 135!

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Glass fiber. Standard high speed steel on this material, 4-5 holes. *Vasco Supreme*, 1400 holes before sharpening.

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SAE 4340. Using 18-4-1 nitrided, customer got 380-400 pieces per grind. *Vasco Supreme* changed matters: 906-1230 pieces.

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Steel plate. Large-diameter rings, 3/16" thick, are nibbled by tool and die cutting inside and outside of circle. *Vasco Supreme* gives twice the production per grind over competitive grade.

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Electrolytic iron powder. *Vasco Supreme* compacting punch produced 4,000,000 parts (gears) during run.

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High silicon sheet. On indexing type lamination die, previous high-carbon, high-chrome steel made 3000 hits . . . *Vasco Supreme* ran 65,000.

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Hard drawn brass and copper. Dies of *Vasco Supreme* provide 300 per cent longer life than 18-4-1 steel.

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Personals . . .

John W. Russell ⊕ has left the Continental Foundry and Machine Div., Blaw-Knox Co., East Chicago, Ind., after five years service as a research metallurgist to become assistant to the works manager of the National Rolls Div. of General Steel Castings Corp., Avonmore, Pa.

Alan Swabey ⊕, a Montreal patent attorney, represented Canada at a special conference of the International Assoc. for the Protection of Industrial Property, held in Zurich, Switzerland, early this year. The conference reviewed proposals for changes in the international convention between the major countries relative to patents and trademarks, preparatory to a diplomatic conference in November when the proposals will be discussed by the governments concerned.

William H. Santschi ⊕ has accepted a position as associate director of research for the Beryllium Corp., Reading, Pa. He comes to the company from Allegheny Ludlum Steel Corp., where he was supervisory metallurgist of special metals.

James C. Sarvis ⊕, a laboratory general mechanic for the past four years with the U. S. Bureau of Mines, Albany, Ore., was recently promoted to physical science aid, and placed in charge of the heat treatment and hydrogen reduction unit of the physical metallurgy laboratory.

Walter Arrowsmith ⊕, formerly on the staff of the research laboratory of Armco Steel Corp., Middletown, Ohio, now holds the post of metallurgist in the material testing laboratory, astronautics division, Consolidated Vultee Aircraft Corp., San Diego, Calif.

William J. Miller ⊕ left the U. S. Bureau of Mines at Rolla, Mo., where he was employed as a physical metallurgist, to take a position as supervising metallurgist of process control with Universal-Cyclops Steel Corp., Titusville, Pa.

David L. Wheeler ⊕, formerly affiliated with ALCO Products, Schenectady, N.Y., is now a metallurgical engineer in the research laboratory of Armco Steel Co., Baltimore, Md.

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Personals . . .

Hubert J. Pessl ⊕ has been appointed director of research and education for the Verson Allsteel Press Co., Chicago. During the past two years, Dr. Pessl has served as a consultant for Verson's research and development center, and until recently was director of Shell Engineering and Research for Gibson Refrigeration Co., Greenville, Mich.

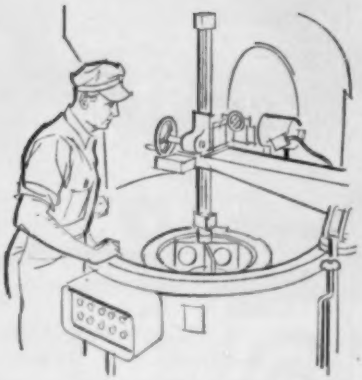
Harold B. Chambers ⊕ has assumed the post of director of metallurgy for Atlas Steels Ltd., Welland, Ont., and now heads all metallurgical functions within the organization. Mr. Chambers, who joined the company in 1931, last held the post of superintendent of inspection and metallurgical services.

Bernard O. Brouk ⊕ is district representative in the Detroit area for the National Bearing Div. of American Brake Shoe Co., St. Louis, Mo. Prior to this position, Mr. Brouk was a sales engineer for the National Bearing Div., and before that saw service as a Lieutenant Commander in the U.S. Navy, assigned to the metallurgical research department of the Bureau of Ships.

Robert H. Goodman ⊕ is now technical service representative in the Philadelphia and metropolitan New York area for the sodium products division of the electrochemicals department, E. I. du Pont de Nemours & Co., Wilmington, Del.

Wylie J. Childs ⊕, a 1943 graduate of Rensselaer Polytechnic Institute, is returning to the Institute this month as an associate professor in the department of metallurgical engineering. Dr. Childs became a research fellow at Rensselaer upon graduation and continued his graduate studies there, receiving his master's degree in 1945 and his doctor's degree three years later. After a short time at Massachusetts Institute of Technology, he joined the faculty of Lafayette College, serving first as associate professor and later as professor of metallurgical engineering and head of the department.

Harold L. Dirkers ⊕ has been transferred from the Detroit office of Wheelco Instrument Div., Barber-Coleman Co. to the division's St. Louis office as branch manager.



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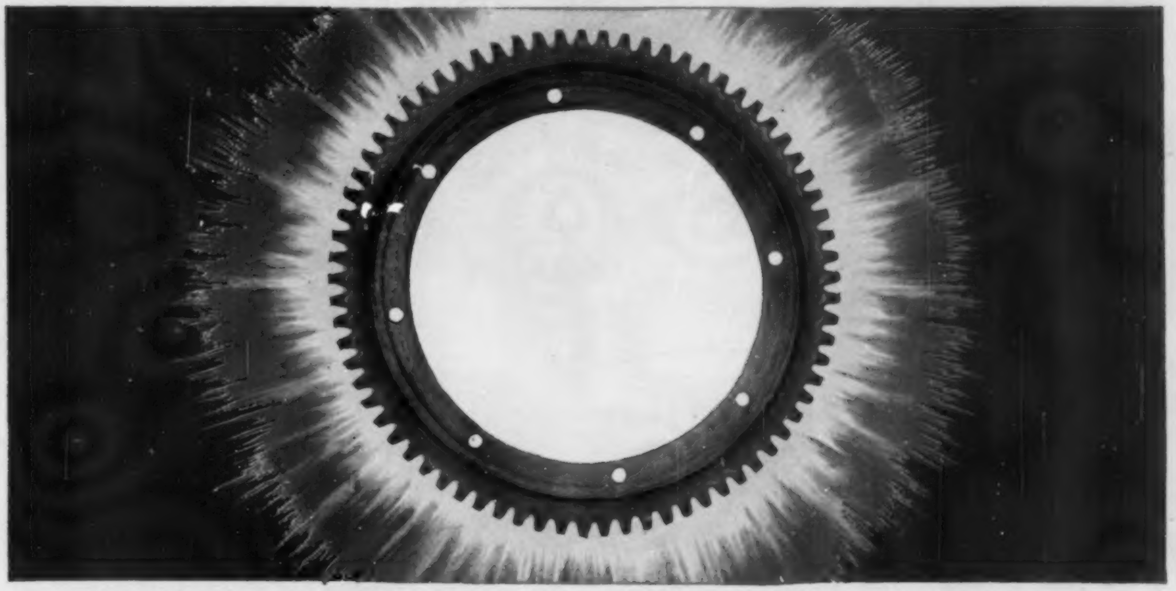

Gears, shafts, pins, wheels, tubes and bars—almost any size or shape of part—or any metal, too—is adaptable to TOCCO hardening, brazing, annealing or heating for forging.

Production Up—Engineers at the Milwaukee Works of International Harvester Company have adopted TOCCO for hardening final drive gears for famous International Harvester farm tractors. TOCCO increases production on the gear shown here from 14 to 35 per hour, 250% faster than conventional heating method, reduces job from a 3 shift to 2 shift operation, even with increased production schedule. Heating time is 35 seconds; oil quench, 60 seconds.

Costs Down—TOCCO cuts cost—saves $82,507 per year on application shown above. TOCCO makes possible use of C-1050 A.R.R. steel instead of expensive A-8645-H alloy steel previously required. TOCCO also eliminates shot-blast, formerly needed to remove scale, and extra machining operations that used to be necessary to compensate for distortion.

Gear shown is 18½" O.D., width of face is 2", weight 34 pounds, 73 teeth. Hardness obtained is 55-66 R.C., using 140 K.W. of 10,000 cycle power.

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Personals . . .

J. D. Nisbet resigned his position as assistant to the senior vice-president at Universal-Cyclops Steel Corp., Bridgeville, Pa., to organize the Allvac Metals Co. in Monroe, N.C. Mr. Nisbet is president of the company, which will specialize in the production of high-temperature alloys.

Donald W. MacKenzie affiliated with Williard, Inc., Philadelphia, since March 1947, has become a partner in William R. Funk Associates, Philadelphia.

William E. B. Mason has been appointed general welding superintendent, thermal products division, Alco Products, Inc., Dunkirk, N. Y. Mr. Mason came to Alco Products as a metallurgist in 1951, and until his appointment was chief, quality control, for the company's Dunkirk plant.

George W. Stamm has been named vice-president and general manager of sales for Crucible Steel Co. of America, Pittsburgh, succeeding **James D. Glenn** who relinquished this post because of illness. Mr. Glenn will remain with the company on a consulting basis. Since joining Crucible as a sales trainee at the St. Louis branch in 1940, Mr. Stamm has served in various managerial positions, including assistant general sales manager at the Pittsburgh office and more recently general manager of sales, a post he will continue to hold.

William H. Graves, a professor in the department of automotive engineering, college of engineering, University of Michigan, was elected vice-president of American Forging & Socket Co., Pontiac, Mich. Professor Graves, a director of the company, joined the faculty of the University of Michigan in 1956 after 37 years service with Packard Motor Car Co., terminating as vice-president in charge of engineering of Studebaker-Packard Corp.

Robert L. Nauert is serving a six-month tour of active duty as a 2nd Lieutenant in the U. S. Army, stationed at Ft. Leonard Wood, Mo. Upon completion of active duty next month, Lt. Nauert plans to return to Blackwell Zinc Co., Inc., Blackwell, Okla., as a metallurgical engineer.

Personals . . .

Harry W. Dietert, chairman of the board, Harry W. Dietert Co., Detroit, was elected president of the American Foundrymen's Society at the 61st annual AFS Castings Congress and 1st Engineering Castings Show in Cincinnati in May. **Fred J. Pfarr** and **Karl L. Landgrebe, Jr.** were elected as national directors of the society. Mr. Pfarr is manager of the Lake City Malleable Co., Cleveland, while Mr. Landgrebe is vice-president of foundry operations for the Wheland Co., Chattanooga, Tenn.

Mark John has been promoted to general claim manager for Joseph T. Ryerson & Son, Inc., Chicago. His new duties will include supervisory work with the nation-wide group of 17 Ryerson steel service plants. Mr. John began his career with Ryerson in 1941, joining the claim department seven years later and rising to head of the department in 1954.

Richard J. Haffeman is now an engineer in the core engineering department of the atomic power division, Westinghouse Electric Corp., Pittsburgh. Before coming to Westinghouse, Mr. Haffeman was assistant plant metallurgist at the John Deer Ottumwa (Iowa) Works of Deere & Co., and prior to that a member of the materials engineering department of the main company at its Moline, Ill., headquarters.

Jack K. Witherington left the Crane Co., Chicago, to serve in the U. S. Army at the Criminal Investigation Laboratory, Ft. Gordon, Augusta, Ga. After leaving the service, he joined Horace V. Witherington, foundry consultant, in Huntingdon Valley, Pa.

Marion M. Fox, a recent graduate from the University of Illinois, is now employed in the metallurgical department of the John Deere Dubuque (Iowa) Tractor Works of Deere & Co.

Thomas J. Schug recently opened a branch office in Charlotte, N.C., for Gros-ite Industries, Winston-Salem, N.C. Mr. Schug, who is manager of the new office, was formerly a sales engineer for the company.

Digests of Important Articles

Welding of Cast Iron

Digest of "The Welding of Flake Graphite Cast Irons, With Particular Reference to the Mechanical Properties of Butt-Welded Joints", by F. Dunn and G. E. Morton, *Journal of Research and Development*, British Cast Iron Research Assoc., Vol. 6, October 1956, p. 364-402.

THE BRITISH Cast Iron Research Assoc. receives many requests for suitable methods of welding broken castings. The Association reviewed current practices and concluded that work would be necessary to develop the required data for flake-graphite cast irons of engineering quality. It was decided to investigate the mechanical properties of butt welds made by oxy-acetylene welding (using cast iron filler rods) by metal arc welding (using nonferrous electrodes of the nickel-iron alloy type), and by bronze welding. The effect of preheating up to 1290° F. was also studied.

Irons of six different compositions considered representative of commercial cast irons were used. Their phosphorus levels were 0.1, 0.5 and 1.0%. Test plates 12 x 9 x 1 in. and 12 x 9 x 3/8 in. thick were cast and microscopic examination of structures made. Filler rods were of the silicon bronze (0.46 and 0.28% Si), nickel bronze (15.6 and 9.7% Ni), and manganese bronze types. The plates were prepared to a V shape.

After welding, each weld was subjected to root, face-bend, and cross-joint tensile tests. A micro-examination was made of each structure. Hardness traverses were made using a Vickers diamond pyramid hardness tester. All mechanical tests were duplicated on unwelded cast irons of the same composition.

From this work it was concluded:

1. With the exception of the metal-arc welds using a nonferrous electrode, the base metal composition has no significant effect on the mechanical properties of the weld.

2. With oxy-acetylene welding using cast iron filler rods, the transverse strength ranges between 66 and 98% of the unwelded material and the tensile strength between 74 and 99%. The hardness in the weld region was higher than that of the base metal.

3. Where base-metal phosphorus exceeds 0.5%, metal-arc welding with nickel-iron alloy electrodes can give difficulties due to cracking. This investigation has shown that phosphorus content is the critical factor. The transverse strength of welded 0.1% phosphorus material ranges between 96 and 100% of unwelded iron with 3/8-in. thick plate, and between 63 and 80% on 1-in. thick plate. The tensile strength ranges between 96 and 99% of the tensile strength before welding. Microscopic examination reveals microstructural changes in the base metal and evidence of weld junction melting and rapid cooling. The result is higher hardness in the heat-affected zone than in the base metal.

4. With silicon bronze welds there is a wide range of mechanical properties. This is attributed to a band of high-hardness material at the weld junction. A subsequent investigation reveals that this constituent depends upon the silicon content of the filler rod and the welding temperature. Transverse strengths are of the order of 60% of the strength of the unwelded material and tensile strengths are of the order of 50%. It is suggested that the silicon content of filler rods be not greater than 0.1%.

5. With nickel bronze welds transverse strengths range between 77 and 100% of the strength of unwelded material. Tensile strengths between 55 and 100% are obtained.

6. In the cases of silicon and nickel bronze welds there is evidence that parent metal temperatures exceeded 1380° F. Interdiffusion between weld and parent metal occurred, which is not desirable for strong welds. A combination of flux and filler rod that flows and wets freely permits the use of lower welding temperatures and less diffusion.

7. Preheating up to 1290° F. does not damage the base metal or produce changes in microstructures. At this tempreature slightly lower hardness and strength are shown. Thus it is desirable to limit preheating to 1110° F., max.

H. J. NICHOLS

Lithium Metal

Digest of "Lithium Metal", by W. F. Luckenbach, *Foote Prints*, Foote Mineral Co., Vol. 28, No. 2, 1956, p. 23-28.

LIGHTEST of all solid elements, lithium appears on the verge of assuming some heavy roles in the future of metallurgy, organic chemistry and nuclear energy. They will involve both the metal itself and its derivatives – the hydride, aluminum hydride, borohydride and amide.

Elemental lithium is a soft, silver-white metal, somewhat harder than sodium and generally more stable at room temperature than the other alkali metals. Fresh surfaces tarnish quickly in air, through formation of nitrides, oxides and other compounds. The metal reacts with water to form hydrogen and LiOH, but the reaction is not as violent as that of sodium or potassium. Further, the heat evolved is not sufficient to ignite the hydrogen, thus reducing the explosion hazard common to other metals in this family.

Commercial lithium may be pur-

Lithium . . .

chased today at 99.8% purity, with traces of sodium, potassium, nitrogen, chlorine, calcium, iron, aluminum and silicon. Density is 0.019 lb. per cu.in., melting point 367° F. and boiling point 2500° F.

Since lithium reacts readily above its melting point with a number of gases to form stable compounds, advantage can be taken of this property in the use of lithium as a scavenger. Metallurgical usage, especially in the casting of copper and its alloys is based upon this property. One pound of lithium, in reacting to form the hydride, combines with the equivalent of 55 cu.ft. of hydrogen gas. Thus, it is used to some extent in preparation of protective heat treating furnace atmospheres.

Alloying with lead and magnesium also has proved practical. As early as 1923, the Germans produced a bearing material they called Bahnmetall (railroad metal), a lead-bearing alloy, characterized by good hot strength. In recent years, the foundry industry has used lithium metal as a deoxidizer, desulphurizer and degasifier for copper alloy castings. Only a small quantity is required in such operations – 0.001 to 0.025%.

The outlook for lithium in the field of organic synthesis is particularly bright. As a catalyst it is efficient, selective and economical. In the polymerization of monomers like isoprene, butadiene, ethylene and styrene, it has proved most effective. Lithium hydride and lithium aluminum hydride act as specific reducing agents to produce selective organic reductions not possible with either sodium or potassium. This has been notably valuable in the manufacture of vitamin A, the antihistamines and antibiotics.

More exciting, however, is lithium's potential use as a coolant or heat exchanger medium in nuclear reactors. Lithium has a heat capacity almost three times as great as sodium, its nearest competitor, and is already in use as a coolant in submarine reactors.

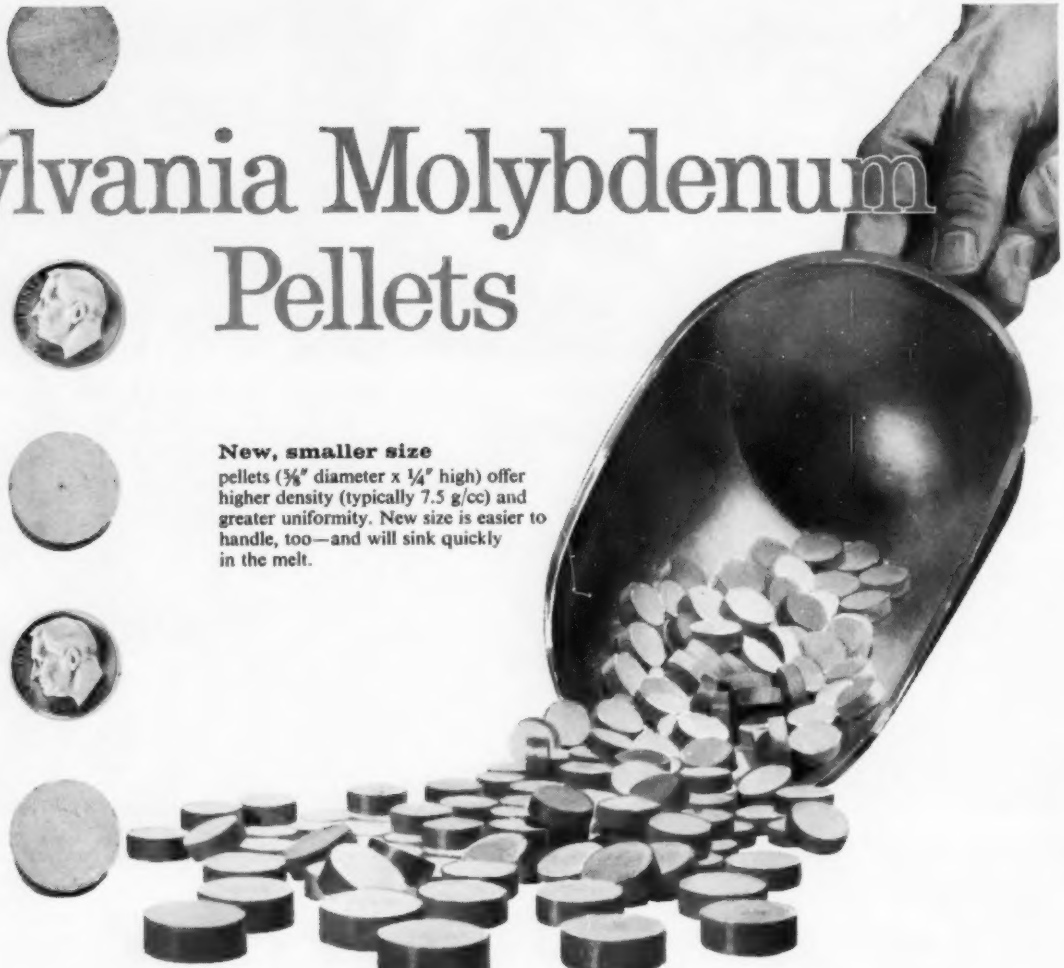
Lithium as a source of nuclear energy has demonstrable physical potentiality at temperatures approaching solar magnitudes. Practicality of such reactions remains to be proved. However, the metal may be viewed in yet another light, in terms of its neutron cross section. Normal lithium has a low, but undistinguished, neutron cross section, but the lithium-six isotope has a very high one (912 barns), and, in contrast, the lithium-seven isotope has one of the lowest (1.0 barn). Dual properties of this magnitude in one element are rare, to say the least. Lithium isotopes, at the moment, are not standard items of commerce.

Reportedly, lithium metal is being used in the production of rocket engine fuel.

Much remains to be learned about how best to handle liquid lithium since it is highly corrosive and will dissolve metals such as copper, zinc, tin and their alloys. As far as is currently known, the most satisfactory materials of construction for containing the molten metal are the low-carbon steels and tantalum.

ARTHUR H. ALLEN

Sylvania Molybdenum Pellets



New, smaller size
pellets ($\frac{3}{8}$" diameter x $\frac{1}{4}$" high) offer higher density (typically 7.5 g/cc) and greater uniformity. New size is easier to handle, too—and will sink quickly in the melt.

—the new form manufactured to specified purity and composition

Sylvania Molybdenum Pellets are designed and manufactured specifically for use in vacuum melting. They provide a readily available source of the best purity molybdenum (typical 99.85%) available on the market. Detrimental impurities are at an extremely low level. This consistent high purity simplifies the calculation of additions to each melt as the usual variations of purity and gas content are eliminated.

By maintaining a high density, the gas content of the pellets is kept well below that acceptable for vacuum melting. In addition, the compact uniform size of the pellets facilitates weighing and charging to the melt.

When you use Sylvania Molybdenum Pellets, you benefit in other ways, too. Their continuous availability means you can plan your production schedules on a long-range basis. Further, their pricing stability permits you to price your own product without having to worry about fluctuating raw materials costs.

Call your Sylvania representative or write for details.

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Musical Metallurgy

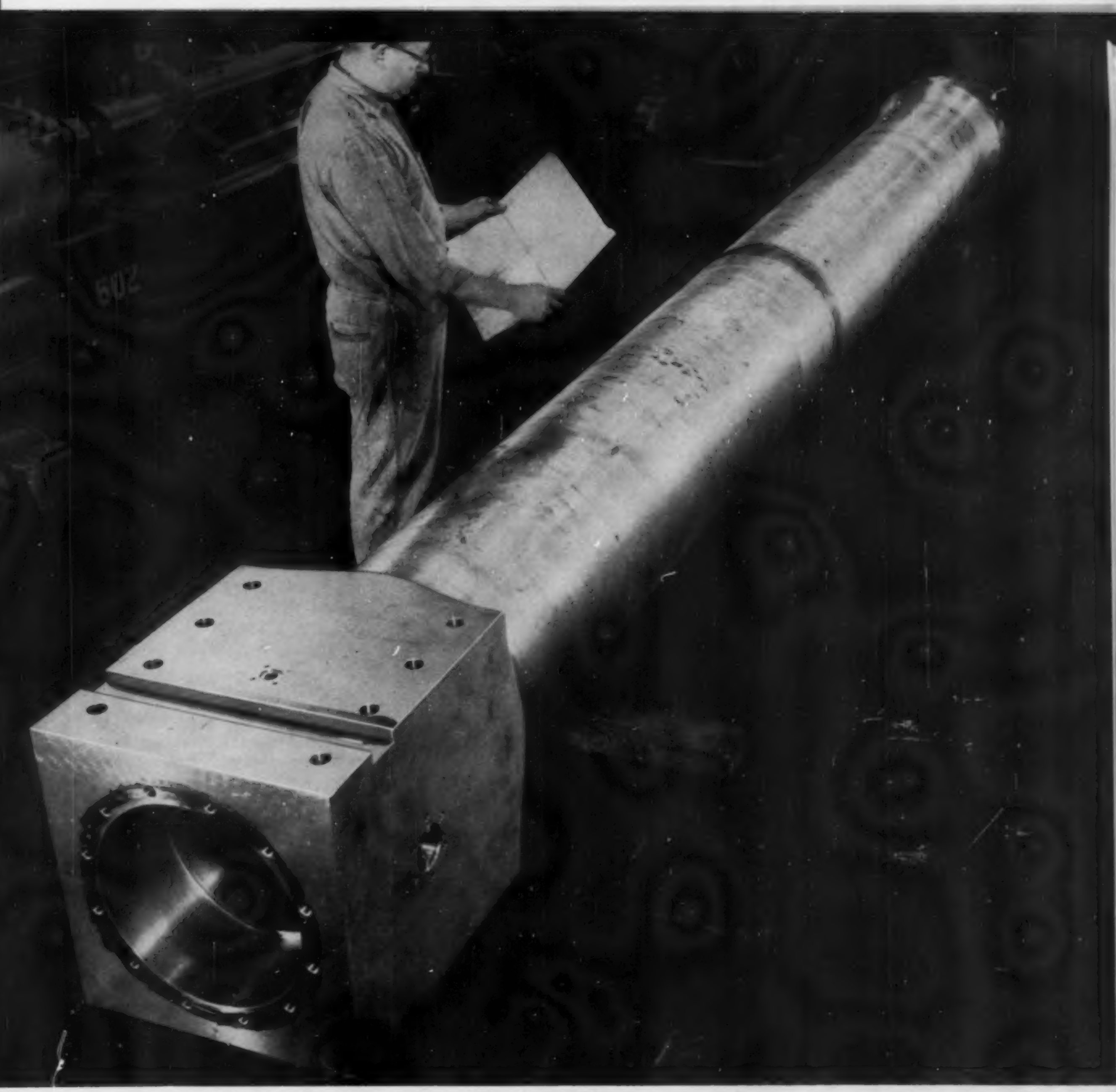
Digest of "Metallurgy in Music Making", by H. H. Symonds, *Journal of the Birmingham Metallurgical Society*, Vol. 36, December 1956, p. 431-463.

Most of us consider that violin strings are made of cat gut; we do not realize that in many instances gut is only the core of the strings, and that in the violin G string, for example, the gut is entirely replaced by a core of steel, wound with two layers of copper wire and a final layer of flat aluminum wire.

Metal is so commonly used in musical instruments that it is difficult to find one that does not have metal in some part of its construction. The piano frame, the brass instruments and many of the component parts of a church organ are fabricated of metal.

In the piano frame it is essential that there be no "jangling" when the strings are struck. Because cast iron has strong damping characteristics, and is easy to cast in a green sand mold, and is economical, it is the preferred material. Although the tensile strength of cast iron is only 10 to 17 tons per sq. in., its compressive strength is much higher. In casting piano frames, special precautions have to be taken to see that internal stresses are not present, due possibly to uneven cooling rates. Areas of very different cross section are heated locally during cooling, to average out the cooling rate of the frame as a whole. Because of its high strength, steel has been tried, bringing down the weight of the casting and eliminating some of the intermediate bars on the frame; however, the higher cost of a steel casting more than offsets the advantages. Aluminum alloys are soft and have relatively poor acoustic properties. An unusual exception was the aluminum frame of the grand piano on the ill-fated Graf Zepplin, where lightness was considered of more importance than anything else.

The numerous problems associated with the production of piano frames have limited competition so that now there are only four firms in the United Kingdom so engaged. The iron contains about 1.4% phosphorus for fluidity, and is melted in a



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A specialist in big forgings, that's who, and that's us . . . one of the very few companies equipped to handle such a big job. When *you* need a cylinder forging like this, we'll do the *whole job*, including final machining, to tolerances as close as ±.001"; or we'll produce in rough finished form with the final machining left to you; or we'll harden and temper the steel, doing the entire job to your exact specifications.

For the hydraulic cylinder in the photo above, we poured an electric steel ingot, forged it, hollow-bored it, lapped it, and polished it to a cylinder finish—we could do all of this . . . do it well and do it economically —because we are specialists and ours is a completely integrated plant. We'll produce *your* big forgings too —exactly to your specifications.

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IRVINE (WARREN COUNTY), PENNSYLVANIA

To see more of "the big ones," and the machinery they're made on, write for Bulletin NFO-2

Musical Instruments . . .

cupola and cast in green sand molds. The final surfacing is done by spraying on a bronze powder held in a cellulose medium.

Organ pipes are of considerable metallurgical interest. While some of the softer toned pipes are made of wood, most of the pipes are fabricated out of tin, lead and zinc. The tonal quality of organ pipes is all-important. The grand diapason tone calls for pipes of tin-lead alloy, the broad tones having the higher lead content and the brighter and more strident notes having a higher tin content. Alloys of 50 to 55% tin are used for the better quality pipe, because during solidification these alloys form large crystals or "spots". This crystal structure gives a particularly rich tone. Why? Here is a problem for the physical metallurgist.

Organ pipes are not, as might be expected, cast to shape but are fabricated from thin cast sheet. The process will be a novel one to most metallurgists. The mold, if such it can be called, is a slab of stone 12×4 ft., covered with a thick resilient layer of twilled cotton fabric. Over this is stretched a sheet of glazed linen. The alloy is melted in an open gas-fired pot with constant stirring. When the melt has reached the soldius-liquidus stage, with the separation of the higher melting point constituents, it is poured into a trough of hard wood, mahogany or lignum vitae. This trough slides rapidly down the casting table on guides. The melt runs out of a slot leaving a thin semi-liquid sheet of metal in its wake. The casting operation takes about 5 sec.; the sheet of 'spotted' metal is left to solidify completely. The size of the 'spots' or crystals is, of course, a function of composition, temperature, rate of casting, and rate of cooling. The resultant sheet is trimmed, rolled up and held ready for forming into the desired pipes. Eutectic tin-lead solder is used to make the required joints.

The making of bells follows the usual foundry method, the alloy used being 80-20 tin-lead, sometimes with additions of zinc and iron. Iron and zinc give more brilliant tone and a greater breadth of tone. Here is another "why" for the physical metallurgist.

Stringed instruments offer perhaps the most unexpected use of metals. Frequency or pitch decreases with increase in length of the strings; it increases with increase in tension, and decreases with increase of mass per unit length. The last item is the basic reason for covering the strings with metal wire. In many instruments the lower or bass strings would need to be either so thick as to have little power of vibration or so long as to be impractical. By covering with metal, a thinner string can have greater weight per unit while retaining its flexibility and power to vibrate freely. Wire as thin as 0.003 in. diameter is used. The new metal strings give an immediate response to all types of bowing. The core of the strings may consist of gut, silk, steel, nylon, or Terylene; over these is wound fine wire of either silver, aluminum, Monel, 80-20 cupro-nickel, copper, silver-plated copper, or gold. It is essential that the wrapping be very tight since any looseness or unevenness of covering results in a false tone. Steel piano wire must withstand extreme intensities of vibration. While at a tension of 150 lb. the highest pitch strings may vibrate as many as 4190 times per second. Such strings will be only a few inches long. The lowest bass string may be 18 ft. long and vibrate only 27 times per second.

In 1930 aluminum violins were made commercially in the United

Musical Instruments . . .

States. The front and back panels and neck and key section were stamped and profiled from an aluminum alloy containing 1% Si and 0.6% Mg. The scroll was made from two thin die castings. The whole assembly was welded together and the final tone was said to compare favorably with that of modern violins made of wood. However, it would seem unlikely that the modern virtuoso would forsake the old-time material. Freedom from warping due to changes in temperature and humidity would be a decided advantage, especially in tropical climates. Other musical instruments such as mandolins and guitars have also been made of light alloys.

The paper also discusses the methods employed in the production of brass instruments, and the production of phonograph records.

Musical metallurgy would seem to be worthy of study not only by those interested in music but by physical metallurgists who will find a challenge in the unexplained action of some alloys.

HAROLD J. ROAST

Russian Work on the Bainite Reaction

Digest of "Transformation of Austenite to Bainite", by L. M. Pevsner, T. D. Kubyshkina, G. M. Rovenskii and A. I. Samoilov, *Metallovedenie i Obrabotka Metallov*, No. 10, 1956, p. 2-20.

THIS PAPER is largely a review of Russian and foreign work on the bainite reaction, although special attention is given to recent research done in the authors' laboratories. The Russian term for bainite reaction is "intermediate transformation", from the fact that in many alloy steels there is a characteristic region in the TTT-diagram associated with the bainite reaction analogous to the "nose" at which the pearlite reaction occurs most rapidly. However, whether or not there is a separate bainite nose for a given steel, the bainite reaction is present in all cases.

The bainite reaction occurs in the temperature range where the rate of

Bainite Reaction . . .

diffusion of carbon is still appreciable but where the diffusion of iron and alloying elements is extremely slow. Thus, the basic difference between the bainitic and pearlitic reactions is that the pearlite reaction occurs by a mechanism involving appreciable diffusion of the matrix atoms while the bainite reaction involves a change in the matrix from the austenite lattice to that of distorted ferrite by a shear mechanism in which coherency is maintained. This mechanism differs from the martensitic reaction in that diffusion permits a redistribution of carbon.

The mode of redistribution of carbon is different in hypo-eutectoid and in hypereutectoid steels. In the course of the bainite reaction in hypo-eutectoid steels the untransformed austenite becomes enriched in carbon, although the degree of enrichment depends on the temperature of reaction and on the alloy content. In hypereutectoid steels, on the other hand, the untransformed austenite usually becomes poor in carbon. In this case the carbon is used in forming carbides of the cementite type which may be the first step in the bainite reaction in some steels. These carbides are only slightly enriched in the alloying element, in contrast to the extreme enrichment often encountered in the pearlite reaction.

The typical retardation of the decomposition of austenite in the upper bainite zone cannot be explained by the enrichment of the austenite in carbon since a similar retardation occurs in hypereutectoid steels although *impoverishment* of the austenite in carbon occurs. It is suggested that the cause of the retardation lies in the "coherency mechanism" of the decomposition of austenite in the bainite region. However, further work is needed on this problem and on the mechanism by which alloying elements affect the bainite reaction. A. G. Guy

Forming Titanium Sheet

Digest of "Forming 6A1-4V Titanium Alloy", by A. G. Lucas, *Light Metal Age*, Vol. 14, December 1956, p. 21-24.

Boeing Airplane Co.'s practice in forming titanium sheets containing 6% aluminum and 4% vanadium is described. The tolerances for conventional assemblies are the same as for aluminum alloys. For resistance welded corrugation sandwich panels, for instance, the tolerances are ± 0.02 to 0.04 in. A heavy steel fixture is used for aging these panels for 4 hr. at 1000° F., as well as in forming, to insure the correct finished size and shape.

Most forming is now done on annealed sheet although the author believes it would be better to form this sheet after the solution treatment at 1700° F. since warping occurs as a result of heat treating and quenching. Roll forming and stretch forming can be done at room temperature provided no bends are made with radii smaller than six times the sheet thickness, but forming by brake or drop hammer must be done above 1000° F. (preferably 1200° F. or hotter) because the ductility does not increase appreciably above the room-temperature value until 1000° F. is exceeded. Above 1000° F. the permissible bend radius is three times the sheet thickness. The titanium alloy RC-70 (99% Ti), and the one with 8% manganese, are more ductile below 1000° F.

The best forming properties in the 6A1-4V alloy are found at 1500° F., but at that temperature the alloy is embrittled by oxygen absorption, the steel forming tools scale and become

(Continued on p. 156)

1 Water-cooled power cables.

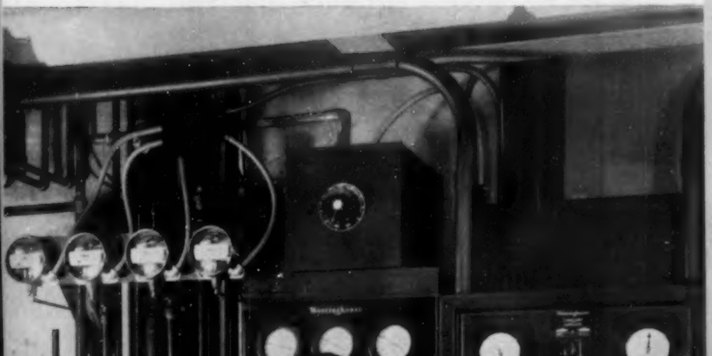
2 Electrode holder.

3 Vacuum-tight seal for electrode housing.

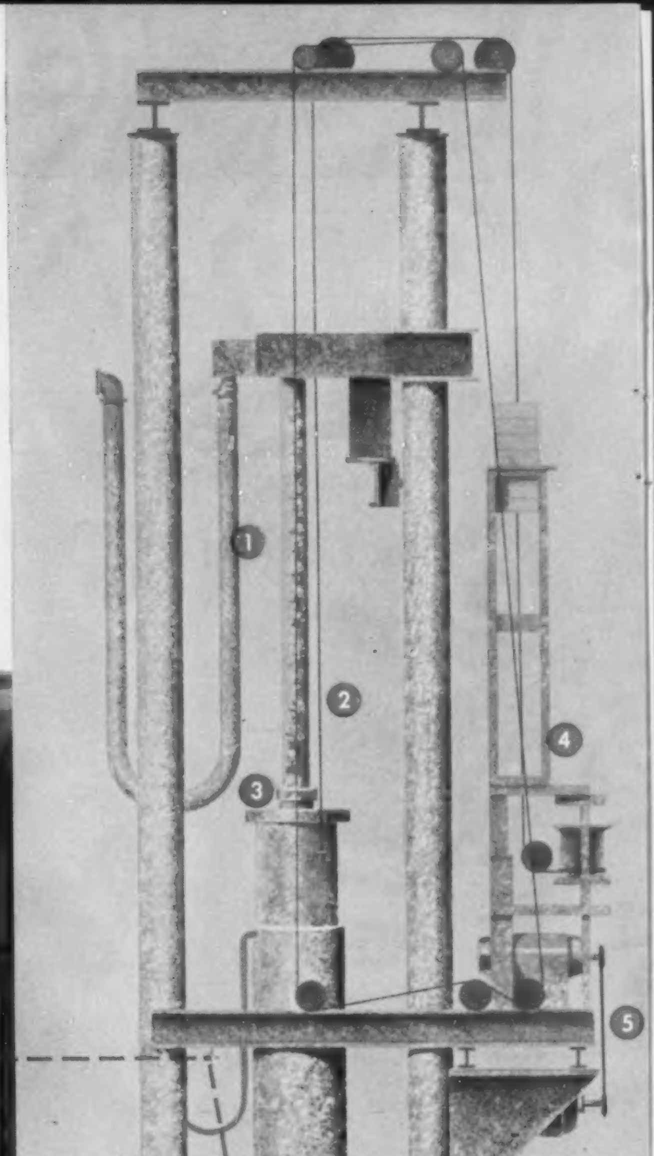
4 Lifting mechanism for electrode housing.

5 Automatic electrode position drive.

6 Electrode guides.



Automatic control panel sequences and monitors vacuum arc furnace operation. Built-in optical system allows operator to observe melting progress.



Forming Titanium . . .

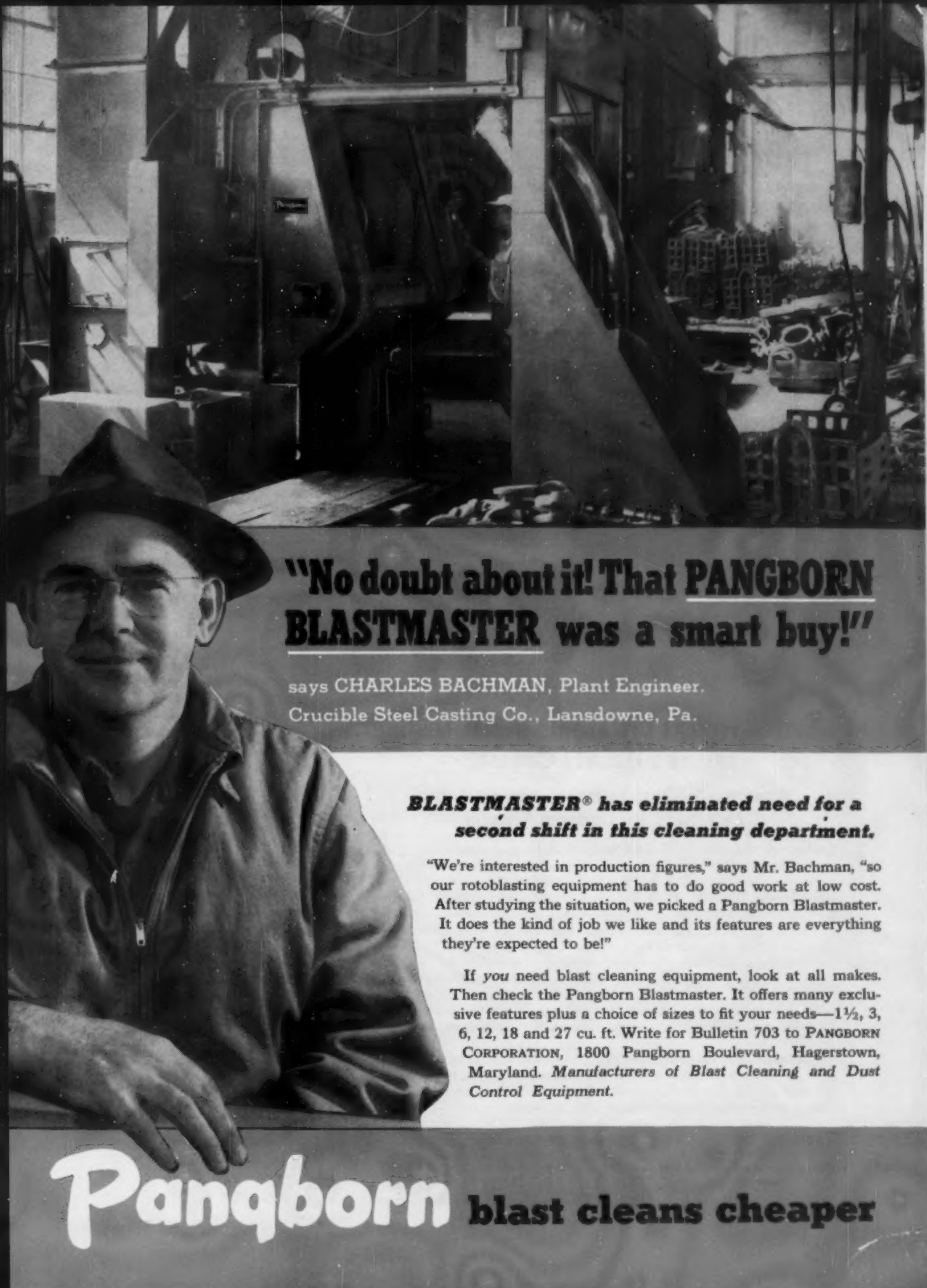
rough, and lubrication is difficult. The titanium alloy is contaminated by oxygen to a depth of 0.004 in. by 30 min. in air at 1500° F., but only traces of contamination occur in 30 min. at 1400° F. The holding time in the interval between solution treatment and heat treatment has an important effect on the properties derived from heat treatment. The properties are adversely affected by holding over 30 sec. at 1400° F., over 2 min. at 1200° F., or over 30 min. at 1100° F.

Colloidal graphite has been used for high-temperature lubrication but is too difficult to remove afterward. A Boeing ceramic lubricant designated F-140-31 has been successful in preventing galling and scale formation at 1400 to 1700° F., and afterward is easily removed by 20% caustic soda solution or by 30 min. in phosphosilicate cleaner. This procedure is followed by a 1 to 3-min. bright dip in HNO_3-HF pickle. Aluminum paint has also been used to prevent contamination during elevated-temperature forming and heat treat operations. Research is in progress on methods for forming so rapidly at high temperature that such protective coatings will not be needed.

An effort is being made to find a die material of low cost having sufficient strength for use at 1000° F., with the titanium alloy blank still hotter. Matched Kirksite dies are used at room temperature with the blank heated to approximately 1600° F. Meehanite cast iron dies can be used continuously no hotter than 800° F. Molybdenum steel dies have been used successfully at 1000° F., with the surface protected from scaling by a 0.004-in. coating of a nickel-chromium-boron alloy, subsequently hand finished.

If the blanks to be heated for forming have a constant cross section, electrical resistance heating provides a rapid and uniform heat.

Propane or natural gas, automatically mixed with air and controlled, and used in a ribbon-type burner, is also satisfactory for heating. Blanks have been heated to 1200° F. in 6 to 30 sec. by these gases. Efficiency is improved by shielding the work while heating. Gas furnaces can also be used for heating if the in-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Forming Titanium . . .

ternal atmosphere is circulated when operating up to 1450° F. or if the temperature is controllable within ±25° F. between 1450 and 1800° F.

Induction heating equipment operating in the radio frequency range is a feasible method of heating moving strips of titanium sheet—a good method for draw bench forming and for Yoder roll forming. Flat strips and formed shapes in 0.040-in. gage have been heated in this way. Strips of 0.08-in. gage up to 6 in. wide, moving at 2 to 10 ft. per min., can be heated to 1500° F. in several seconds. Very high frequencies give rapid surface heating, but the heat does not penetrate sufficiently.

Electric cartridge and tubular heaters can be inserted in steel dies or die holders for attaining the proper forming temperature up to 1200° F., if they are suitably spaced and fit the receiving holes closely.

George F. Comstock

Measurement and Control of Gage in Strip Rolling

Digest of "The Continuous Measurement and Control of Gage in Strip Rolling", by G. W. Alderton and W. C. F. Hessenberg, *Metallurgical Reviews*, Institute of Metals, Vol. 1, Part 2, 1956, p. 239-269.

This paper is a review in four sections of existing practice on the subject in the United Kingdom. The first section deals with methods of continuously gaging strip at the rolling mill. The second section treats the causes of gage variation in rolling and the third summarizes the techniques of gage control. Section four takes up the simultaneous measurement and control of reduction, which is closely related to gage, and briefly touches on the subject of gage control in tandem rolling mills.

Continuous Gaging Methods — The continuous measurement of gage is a requirement arising from the increasingly high speed of modern rolling mills. Measurement of the moving strip by manual methods as it emerges from the rolling mill is now quite impracticable, since several thousands of feet of strip may have been rolled before the measurement is obtained. The demands for closer gage tolerances and even higher speeds are strong incentives for the use of continuous gaging in hot and cold rolling.

The following types of continuous gaging techniques are described by the authors and compared as to relative merits and limitations: continouous contact gages mechanically operated; radiation gages, based on either absorbed or scattered radiation and using X-rays or gamma rays; magnetic and eddy current gages; ultrasonic gages; and the roll-force gaging principle which utilizes the rolling mill itself as the measuring instrument.

Causes of Gage Variation — Certain important causes of gage variation such as the mill spring effect, lubrication effect, and thermal effect are presented and discussed in some detail. The mill spring effect, for example, results from the fact that during rolling the force tending to separate the rolls is balanced by loading them at each end through

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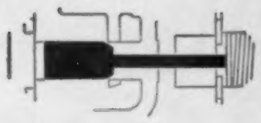

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One-piece bevel gear and shaft

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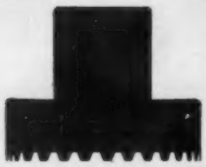
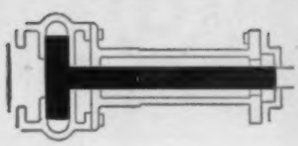


Spline-toothed coupling and shaft



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Gaging of Strip . . .

screws, and as a result the component parts of the mill are distorted in a nonuniform manner. The frame is stretched and the screws and chocks compressed, while the rolls are flexed between the neck and the center. There is also considerable distortion of the rolls, making them noncircular in section and eccentric to the axis.

All of these distortions may not amount to more than a few thousandths of an inch of roll face separation at full load of some hundreds of tons, but the over-all thickness of the strip may actually be less than this, and the permissible tolerances may be an order of magnitude lower. Thus one of the basic problems in gage control is how to position a force of several hundred tons to within a few thousands of an inch with a mechanism having relatively so large a degree of resilience.

Control of Gage – Several factors have combined to make the control of gage variation a matter of ever-increasing importance. There is a constant demand from the user of strip for closer gage tolerances in rolling, partly because his machine can more easily handle uniform material, but also because of the wastage resulting when wider tolerances are permitted.

At present, gages are usually controlled manually by the rolling mill operator. The limitation of manual control, however, is the difficulty of the operator to act quickly enough. This question of speed of response is of great importance, since at high strip speed a gage error must be corrected quickly or a considerable amount of off-gage strip will be rolled.

Automatic controls can be made to operate much faster than can manual controls, and the difficulties which have hitherto stood in the way of their application to rolling mills are steadily being overcome. Thus it is concluded that speed of response is perhaps the most important factor in automatic gage control. Consequently the most promising methods are those providing for accurate and quick response to gage sensing devices.

A bibliography of 45 references is appended to the paper.

W. W. Austin

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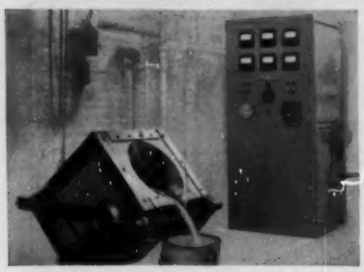

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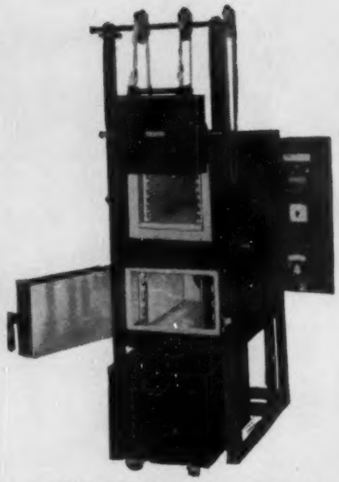

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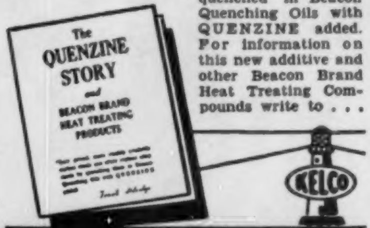

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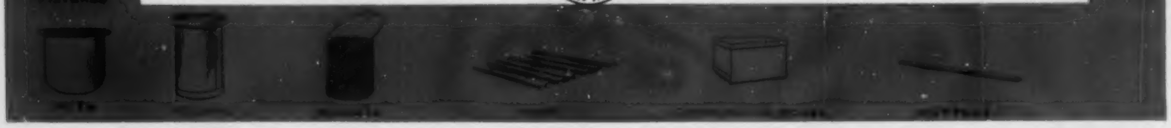

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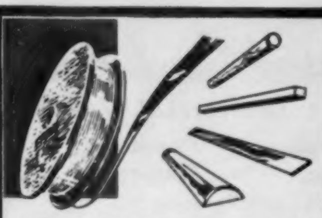

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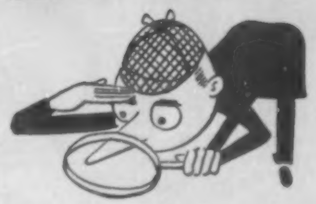

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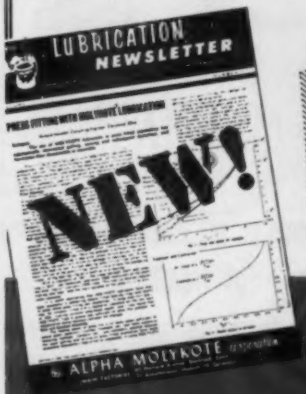

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Methods of Identification and Sorting of Scrap

Digest of "The Sorting of Scrap Metals and Alloys", by E. Scheuer, *Metallurgical Reviews*, Vol. 1, Part 3, 1956, p. 339-378.

THE SORTING of scrap for recovery of specific metal content is an important industrial process and as such is subject to restrictions, complications, and simplifications imposed by economic and commercial conditions in the metal industry. The ultimate controlling factor in determining the optimum sorting effort advisable in practice is the increase in value of the product. Selection of the methods to be employed will depend on the following considerations:

1. Requirements in labor, equipment, and material for achieving a given degree of segregation. These requirements will depend upon efficiency and convenience of the method of identification. Here it is noted that of the infinite number of possible alloy compositions, only a few are in industrial use, and very often only a fraction of these can be expected to be present in a given lot of scrap. As a consequence, the identification problem is often reduced to distinguishing between a very small number of alternatives. This permits a substantial simplification of the methods used.

2. Size of the individual pieces to be sorted: The effort required for identification is essentially independent of the size of the pieces down to quite small dimensions. The economic effect, however, is directly proportional to the size; thus the upper economic limit for sorting decreases in proportion to the size of the piece. Consequently, the size, to a large extent, controls the limit of economic practicability in sorting. The smaller the pieces the more rapid and mechanized are the methods required to make sorting a commercially successful proposition.

Some requirements for useful identification methods are:

1. The method must give reliable results with a minimum of time and effort, in order to permit the identification of pieces in the normal range of size without undue expense.

2. The method should preferably be simple enough to be carried out


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Sorting of Scrap . . .

by unskilled or semiskilled operators.

3. The sensitivity of a given method can often be reduced in favor of a saving in time and skill required without detriment to efficiency, since only a limited number of alternatives need to be distinguished.

The following specific methods of identification have been found to meet these requirements and are used commercially either singly or in combinations:

Appearance – The appearance of a metal is the chief traditional means of identification, especially in nonferrous alloys. The color of clean metal distinguishes between the established alloy specifications.

Chemical Analysis – Qualitative or semiquantitative chemical tests are widely used in the identification of scrap. The time taken for such tests is on the order of 2 to 5 min., but by carrying out tests in groups of 10 to 20 as many as 80 to 90 tests per hr. can be made by one experienced operator. Tests of this kind require a small but definite amount of chemical equipment and skill, and can be conveniently carried out in the field. Such tests are based mainly on color reactions.

Spectrographic Analysis – This method can give a complete quantitative analysis in a few minutes if the general type of alloy is known. Satisfactory qualitative identification can be made on specimens of odd and unknown compositions. The spectrograph, therefore, is potententially useful as a means of identification for sorting. Its practical utilization, however, has been quite limited, primarily because of bulk and expense of equipment and accessories, and second because of the rather high degree of operating skill required.

Mechanical Properties – Frequently simple mechanical tests form an important part of traditional sorting and identification. They are of a very practical and qualitative nature, and are of extreme simplicity. For example, variations in hardness, strength, and ductility are frequently correlated with composition within a known group or class of alloys.

Physical Properties – Variations in density, melting point, magnetic and electrical properties, and to a lesser

Sorting of Scrap . . .

extent, thermo-electrical properties, have found some use in the identification of scrap metals. Grinding or spark testing is applicable to certain groups of metals including the ferrous alloys, and a fairly accurate evaluation of chemical content may be obtained in this manner.

In addition to a comprehensive summary of methods of identification, this paper contains an extensive description of the actual practices of sorting. Included are hand sorting, mechanized sorting by magnetic or by density methods, and liquation. In the latter method metals of high melting point are separated from low melting point materials by melting and draining off the low melting material.

Specific plans for sorting of aluminum alloys, copper alloys, lead, tin and their alloys and the recovery of zinc scrap are included.

W. W. AUSTIN

Device for Wear Testing of Coatings

Digest of "A Device for Testing the Wear Resistance of Surface Coatings", by Jack McCarthy and James Morgia, *Plating*, Vol. 33, October 1956, p. 1248-1250.

LABORATORY DEVICES in common use for evaluation of abrasion and erosion resistance of surface coatings are of two basic types. One involves the action of an abrasive wheel against the coating under controlled conditions of pressure and speed, using wheels of specified abrasive characteristics. The wear resistance is given in terms of number of cycles of rotation to cause break-through. The second type involves the action of a stream of abrasive particles directed against the coated surface under controlled conditions of particle size, flow rate, and impingement velocity.

Both types of tests have several inherent disadvantages. The abrasive wheel is subject to clogging and smoothing through wear. Both of these conditions alter test results. The conventional flow-type device is sensitive to variations in flow rate of abrasive material, making it very difficult to maintain uniform testing

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Wear Testing . . .

conditions and giving irregular results.

Because of these disadvantages, and because of the need for greater reliability a new apparatus known as the Rotobrader was devised by the authors to permit more precise and rapid determination of wear resistance. The new device is based upon the falling abrasive method but with two important modifications: First, the sample is revolved at high speed through the path of the falling abrasive, giving results more rapidly, and second, two samples are run simultaneously, one of which may be a standard and the other the sample to be tested, thus giving a reliable comparison of the relative merits of the two coatings.

A detailed description of the Rotobrader is given by the authors, indicating that it is a simple, inexpensive device that may be constructed from standard laboratory materials and appliances. Several criteria, including the time, the number of revolutions, or the weight of abrasive material consumed to cause failure, may be employed in the evaluation of results. Potential uses of the device include the testing of various types of anodic coatings, paint coatings, and certain wear conditions encountered in aircraft flight.

W. W. Austin

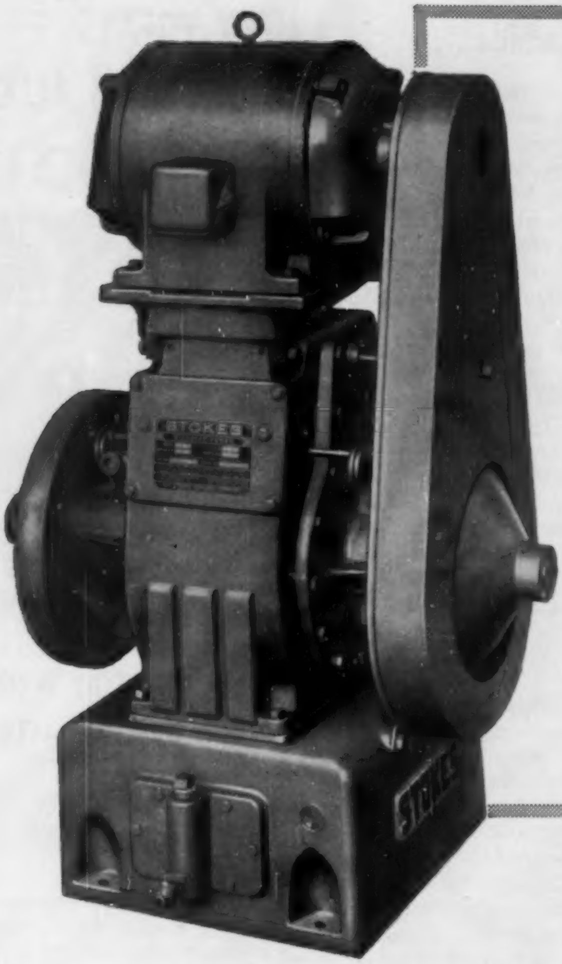
High-Density Silicon Carbide

Digest of "Pressure-Sintered Silicon Carbide," by R. A. Alliegro, L. B. Coffin and J. R. Tinkelpaugh, *Journal*, American Ceramic Society, Vol. 39, November 1956, p. 386-389.

The mechanical properties of cermets are always improved by increasing the density of the sintered material. Hot pressing, or pressure sintering, is the most efficient method for obtaining high-density products. The authors of this paper demonstrate that silicon carbide can be produced with a density of about 98% of the theoretical value.

The equipment for hot pressing consists of a graphite die, insulated with carbon and heated by induction. Pressures up to 10,000 psi. and temperatures up to 4650° F. are obtained. The authors state that the grain size of the silicon carbide powder does not seem to have a significant effect on the density of the final product, but they do not present any data on actual measurements made with various grain sizes.

The effect of metallic additions to the silicon carbide powder was investigated, and in general, higher densities were obtained with these additions. The effects of 17 metals were determined by adding 3 mole-% of metallic binder to the carbide powder. These metals are listed as follows in order of increasing efficiency: Mg, Ta, Co, Ba, Mo, W, Sr, Cu, Mn, Zr, B, Ni, Li, Ca, Cr, Fe, Al. The density of the specimens containing either Fe or Al was markedly higher than that of the specimens containing any of the other metals. The addition of two metal binders instead of one was also investigated, by keeping the aluminum concentration the same (3



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Silicon Carbide . . .

mole-%) and adding 3 mole-% of one of the metals listed above. No significant improvement in the density of the hot pressed compacts was found even in what would appear to be the most favorable condition – namely, the addition of 3 mole-% Fe and 3 mole-% Al.

The mechanism by which aluminum increases the density of hot pressed silicon carbide was not thoroughly investigated. Aluminum was added either in the metallic form or as aluminum oxide, (which was reduced in the hot pressing operation). Chemical analysis and X-ray diffraction methods failed to reveal the presence of aluminum carbide in the sintered product. The authors mention, however, that there was a slight shift in the X-ray diffraction pattern of the aluminum bonded silicon carbide. It is unfortunate that they do not give more details about the magnitude nor the direction of the shift. These two observations could lead to interesting speculations on the possibility of substituting an aluminum atom into the silicon carbide lattice, and this "solubility" of aluminum into the carbide may have something to do with the improved bonding of the carbide grains.

The addition of either aluminum or iron had a definite effect on the minimum temperature required to obtain maximum density. Without addition, increased density was obtained for temperature above 4500° F. With additions, this threshold temperature was somewhere around 3700° F. These results are of great practical importance, since any reduction in the processing temperature means longer die life.

The mechanical properties of the hot pressed silicon carbide specimens were investigated, but the rather limited amount of data given in the paper do not lead to any definite conclusions concerning the effect of the various metallic binders. The strength of a dense carbide containing 1% aluminum was 54,000 psi. at room temperature and 70,000 psi. at 2500° F. With an aluminum content of 5%, the room-temperature strength was higher, namely about 61,000 psi., but the strength dropped with increasing temperature, and reached 44,000 psi. at 2500° F. This behavior is probably due to the

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presence of metallic aluminum around the carbide grains.

Oxidation tests were made in a temperature range of from 1800 to 2500° F. After an initial gain in weight of about 0.3 g. per sq. cm., no measurable oxidation took place during an exposure of several hundred hours, and the depth of the oxide layer remained very small.

Judging from the experimental results described in this paper, hot pressed aluminum or iron-bonded silicon carbide cermets might become extremely important high-temperature materials.

POL DUWEZ

A New Type of Fatigue Testing Machine

Digest of "An Unconventional Type of Fatigue Testing Machine", by F. Aughtie and H. L. Cox, Reports and Memoranda No. 2833, Aeronautical Research Council, Ministry of Supply, H. M. Stationery Office, London, 1955, 12 p.

For testing materials under static loads, the whole structure of the machine, including the straining mechanism, must be of sufficient strength and stiffness to sustain the magnitude of the maximum load.

In a fatigue testing machine, the direction of stressing is reversed at uniform controlled rates and the total load required to impose and maintain the stress in either direction is applied. Due to the elastic properties of the test piece energy is stored up and returned to the actuating mechanism every half cycle, so there is superimposed a cyclic variation in load, which is smoothed by the provision of a flywheel.

The unconventional nature of the fatigue testing machine proposed in this paper is that the specimen is mounted integrally in a spring-mass system which vibrates in resonance. The spring system and the specimen are alternately in a state of strain and the sum of their energies is constant. In a resonant system the energy stored in the test piece is returned to the spring-mass system and back to the test piece in successive half cycles. External energy is required only to start up the test and to replace losses due to damping. The total energy required to maintain the system in resonant oscillation is very small. The frequency will depend on the design of the system. The amplitude is controlled by the energy supplied and will decide the load for the test.

The method of applying the principle of resonance is discussed with particular reference to the design of the spring and mass system, the control and maintenance of amplitude and the effect of variation in stiffness of the test piece during the test. The design of a torsion fatigue testing machine is used as an example. The principle of calculations for springs and masses for a torsion fatigue testing machine is also discussed.

The essential problem of starting

up the machine with only the power needed to maintain it in resonance is met by using a "slipping clutch mechanism" invented by F. Aughtie.

The exciter consists of a variable throw crank and a rod connecting to the straining mechanism. If the system were solid the full load would be needed for the first quarter revolution but the connecting rod ends in a clutch mechanism. The end of the rod forms a piston which connects with the clutch housing by two plastic blocks. The coupling may be loose and no energy is transmitted or it may be adjusted so that frictional contact transmits the required energy. In operation the clutch is left free and the motor is run slightly in excess of resonant frequency. The clutch is then adjusted by screw or oil pressure until the clutch ceases to slip and maximum energy is transmitted.

Though published in 1955, a sub note to the title states that it was originally communicated in 1935. Between these dates several publications have appeared and amplify the original paper.

Cox and Coleman (*Journal*, Royal Aeronautical Society, January 1950) give a technical description of the basic principle and methods of excitation and control. They illustrate with photographs the application of the technique for testing small wing segments, a helicopter blade 13 ft. long and an elevator hinge bracket of magnesium alloy. R. B. Heywood (*Schweizer Archiv*, August 1953) describes briefly the slipping clutch exciter and illustrates its use in vibrating wings of various aircraft.

H. L. Cox and N. B. Owen (*Engineering*, April 22, 1955, p. 500-504) describe in detail the construction and operation at the physics division of the National Physical Laboratory of a machine with a ten-ton range and frequency of 2000 cycles per min., operated by this principle of a mass spring loading element and friction clutch. Data are given from fatigue tests on 1-in. diameter short link chains made of wrought iron. The tests required some 650 million stress cycles.

All the machines described have been made by the workers concerned but a commercial machine of this type is available from a British manufacturer, Samuel Gill & Sons (Engineers) Ltd., Coventry.

JOSIAH W. JONES

Brittle Fracture

Digest of "Some Thoughts on Brittle Fracture", by Eduard Houdremont and Heinrich Mussman, *Stahl und Eisen*, Vol. 76, July 12, 1956, p. 903-907.

A CRITICAL assessment is made of the different methods of representing the temperature of transition from a ductile to brittle fracture. The importance of the value of the energy absorbed in the process of the fracture is also discussed.

At the present time the concept of the transition temperature is explained in terms of the relative variation of the yield point and cleavage fracture strength with temperature. The cleavage fracture strength may be defined as the normal stress to

Brittle Fracture . . .

the cleavage plane of a crystal which is sufficient to cause fracture along this plane. With falling temperature the yield point steadily increases while the cleavage fracture strength decreases. The temperature T_k where the cleavage fracture strength is the same as the yield point is defined as the transition temperature. Below this temperature the cleavage fracture strength will be reached before the yield point and failure will occur in a brittle manner. This explanation of the transition temperature, however, is not absolutely correct. The yield point and cleavage fracture tenacity are plotted on the same curve and although their dimensions are the same, their physical significance is different. The yield point is a property from which it is possible to state, on the basis of suitable flow conditions, when permanent deformation for the multiaxial state will occur. On the other hand, neither from the cleavage fracture tenacity nor from the tensile strength can corresponding conclusions be drawn for a multiaxial stress condition.

It is probable that if very high normal stresses occur due to the notch effect, at a low enough temperature, they can exceed the brittle fracture limit before exceeding the yield point so that deformation is limited. This same effect can be obtained at high loading speeds when the rate of propagation of the elastic deformation exceeds the plastic deformation speed.

The steep decline of the notch impact versus temperature curves at the transition temperature is accompanied by a decrease in the permanently deformed volume. A further decline which is sometimes noted at low temperatures in the range of the completely brittle fracture may be due to the fact that the elastic strain continues to decrease. The fracture is propagated through inclusions and crystallites and as the temperature is decreased the fracture path becomes more direct.

Deformation of a metal is considered either elastic or plastic.

Brittle Fracture . . .

During fracture of an impact specimen the energy absorption may be split into the work done in the elastic deformation (A_{el}), and the work done in plastic deformation (A_{pl}). It can be shown that

$$A_{el} = Ag + Av$$

where Ag is the energy for pure shear strain of the part and Av is a pure volume-elongation energy value. For the plastic component of the energy

$$d\,A_{pl} = k \cdot \gamma \cdot dV$$

where k is the compression modulus, V the volume and γ the deflection.

With falling temperature the shear modulus and compression modulus increase and thus Ag and Av decrease. For the plastic component with falling temperature k increases, but γ decreases. Thus, the total energy for fracture is decreased.

Modern theories tend to disregard the pre-existence of Griffith cracks in ductile metals and assume the piling up of dislocations to be the cause of the crack which can initiate brittle fracture. However, the theory does not explain why the cleavage fracture takes place on the (100) plane.

W. A. Morgan

Continuous Casting of Steel

Digest of "Development of Continuous Casting at Atlas Steels, Ltd.", by William W. Jacobs, *Iron and Steel Engineer*, Vol. 33, December 1956, p. 92-97.

The first production unit for the continuous casting of steel sections is installed at Atlas Steels, Ltd. in Welland, Ont. This plant uses the Rossi-Junghans method and pours heats of 8, 14, 30, and 35 tons from the various furnaces. Most of the heats poured at the Atlas plant are special steels such as toolsteels and stainless steels.

The building itself is 85 ft. high, the casting floor 31 ft. above ground level and the discharge pit 20 ft. deep. The casting department is adjacent to the melt shop and the molten metal is transported in a covered insulated ladle. The layout of buildings and equipment makes it necessary to transfer this ladle 165 ft. on a ladle car and over a turntable to position it under the crane in the casting department.

The four levels of the machine, from the top down, consist of the casting floor, the spray floor, the machinery floor and the cutting floor. The ladle tilting equipment and the oscillating mold are on the casting floor. The spray floor houses the spray chamber where the cast billet is cooled. On the machinery floor are the main drive motor, the pinch rolls and the oscillating equipment. On the cutting floor are the cutting torches and discharge equipment.

Molds in use are 4¼ in. square, 5½ × 7½ in., 2½ × 17 in., 5½ × 21½ in., and 6½ × 24 in. These molds are 20 in. long and are made of oxygen-free high-conductivity copper. They are provided with vertical passages for cooling water. These passages contain restrictor rods which confine the water to a 1/16-in. annulus. Cooling water volumes are as high as 300 gal. per

Continuous Casting . . .

min. on the largest mold at a pressure of 60 psi.

The mold is mounted on a table which oscillates during casting. The downward travel of the mold is at the same speed as the rate of withdrawal of the casting (three-fourths of the cycle). The upward movement is three times as fast (one-fourth of the cycle). The oscillation is effected by a double lever and cam system. These are driven by the same 15-hp. motor which drives the pinch rolls.

The bottom of the mold is formed by a starting bar or "dummy bar". This dummy bar has one or more large-headed bolts inserted in the top to which the first metal cast attaches itself. The dummy bar is supported by two sets of pinch rolls. When the process starts, these pinch rolls revolve, pulling the dummy bar down, and with it the newly solidified bar or slab.

The hot castings upon leaving the mold are pulled by pinch rolls into a spray chamber where they are sprayed with water to complete the solidification and further cool the castings. Water supply is automatically varied according to the section size.

The cooled castings then enter the cutting section where acetylene burners, located on opposite sides of the casting cut the billets to the desired length and weight (8 to 16 ft. long).

In early operations with this equipment many difficulties were encountered and a large amount of experimentation was necessary to determine the best procedure for making the best quality casting for the different billet sizes; steel composition also made special precautions necessary. Careful control of at least nine variables was required to produce good-quality castings.

Temperature of the metal in the ladle had to be adjusted for each analysis poured. Too high a pouring temperature caused breakouts below the mold because of too thin a solid skin and also contributed to many surface defects. Low pouring temperatures caused freezing in the ladle. Cooling water supply to the outside of the copper mold must also be carefully regulated for each size of casting.

Metal is poured over the lip into a tundish into the mold. Many difficulties were encountered in the design of the pouring spout, due to entry of slag in the mold, refractory erosion, uneven pouring stream, control of metal level in the tundish, and heat loss. These were overcome only by tedious trial and error and still present problems.

Proper lubrication of the mold surface is critical to prevent sticking of the steel to the copper mold. Rapeseed oil is used and is delivered through drilled passages in the mold; amount of oil supplied is controlled by a variable speed drive on the lubricator. An atmosphere of propane gas is maintained above the liquid metal in the mold to prevent oxidation.

The most important part of the process with regard to internal quality is the spray cooling. A properly balanced spray pattern is necessary to produce a bar free of center

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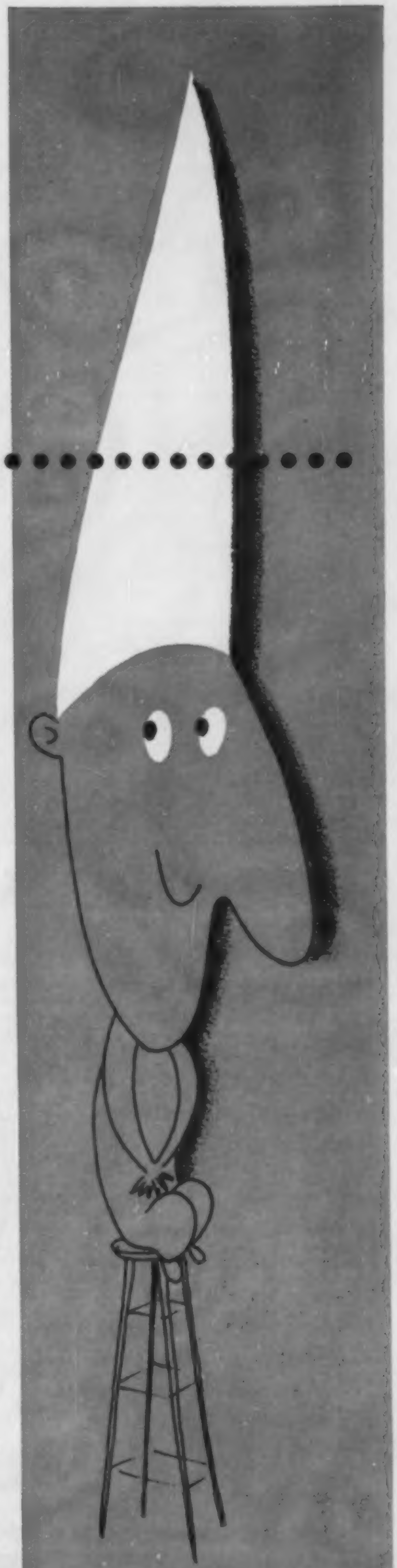

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Continuous Casting . . .

cracks. This involves the cooling along the length of the bar, around its perimeter, actual area covered by the sprays, distance of the nozzles from the casting, total amount of spray water used and other factors. Excessive cooling can be the cause of internal cracks but insufficient cooling on certain shapes can also cause internal cracks. This applies particularly to a rectangular section, where the edge is undercooled in relation to the face. Insufficient cooling can cause a bulge in the bar due to the thin shell being unable to withstand the ferrostatic pressure of the molten crater. Various weird phenomena can be caused by improper spray cooling.

In melting, aluminum is often added to the steel for purposes of deoxidation, grain refinement and special properties. It was found that aluminum contents in excess of 0.02 to 0.04% (depending on grade), make it extremely difficult to cast. High aluminum invariably causes the tundish nozzle to skull up to such an extent that casting is impossible. For toolsteels, this problem has been overcome by using vanadium for grain refinement. For grades where aluminum is necessary, a method of adding aluminum in the mold during casting is being developed.

Hydrogen presents somewhat more of a problem in continuous casting than in conventional ingot pouring. Heats which produce acceptable quality ingots may produce continuous cast billets with subsurface gas holes. Apparently, the hydrogen content of steel for continuous casting must be lower than for ingot casting.

One of the main advantages to be gained from continuous casting is an improvement in yield of approximately 10% over conventional ingot practice. This, of course, is due to the elimination of hot top and butt discard. In continuous casting, the cut lengths can be adjusted to the requirements of the order, eliminating "shorts" which frequently occur when cogging ingots.

In addition to these savings, the use of continuous casting can eliminate or reduce subsequent operations. For example: a $5\frac{1}{2} \times 21\frac{1}{2}$-in. continuous-cast slab can be reduced to $2\frac{1}{4} \times 19$ in. for the strip mill in 13 passes on the bloomer. Using a 22-in. ingot, a total of 32 passes is required. Furthermore, depending on the individual conditions, blooming mill and soaking pit installations could be eliminated completely with a considerable reduction in capital investment.

The very fact that the process is continuous is one disadvantage in that it must remain continuous for the full period of the cast. If trouble of a major nature occurs, such as a cutting failure or nozzle freeze-up, the process cannot be interrupted temporarily and then resumed. What is left in the ladle is either scrapped or, if possible, poured into conventional ingots.

The continuity of the process depends on careful attention to details to insure that each phase of the operation will function properly.

E. C. Wright

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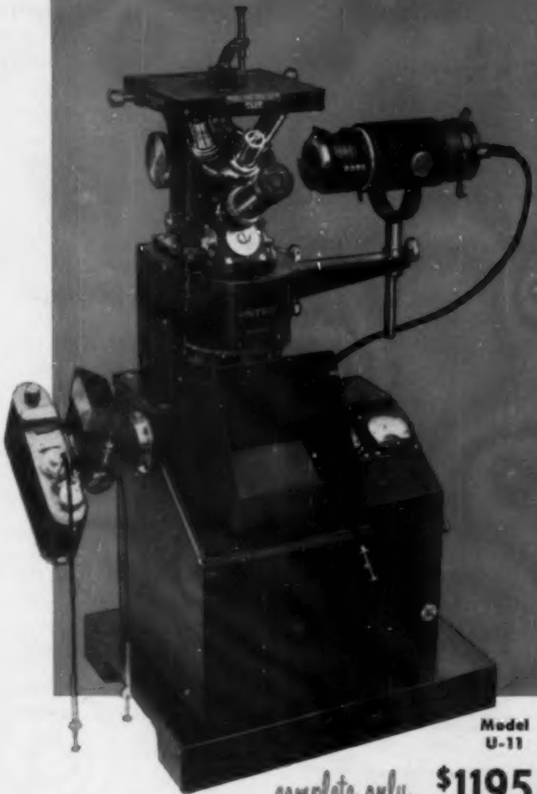

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Hot Cracking of Stainless Steel Welds

Digest of "Hot Cracking of Stainless Steel Weldments," by P. P. Puzak, W. R. Apblett and W. S. Pellini, *Welding Journal* Vol. 21, January 1956, p. 9s-17s.

CRACKING DIFFICULTIES have been encountered in welding castings or heavy forgings of Type 347 stainless steels for use in high-temperature power plants. Such cracking occurs immediately after welding or after stress relief or full heat treatment of welded assemblies.

The hot cracking of weldments is considered to be due to the same factors that determine the hot tearing of castings, namely, coarse-grained structure and a concentration of low melting point constituents at grain boundaries. A research program to obtain basic information on the mechanism of cracking and to evaluate the effects of different metal and processing variables was carried out.

The 1⅛-in. plate was rolled with varying reductions from the original ingot so that both fine-grained and coarse-grained structures were obtained. Three heats of Type 347 and two heats of Type 304 stainless were included, the compositions being such that all the material would be fully austenitic in the as-forged state with the exception of a low-carbon Type 304. Welding electrodes depositing weld metal of 0, 4, 8 and 11% ferrite were also included in the study.

Hot Cracking Characteristics— The finger test, which consists of depositing a bead weld across tightly compressed bars, was used to study hot cracking characteristics. The junction between the bars provides for the development of a gap which simulates the stress and strain condition imposed on a weld solidifying in the presence of a transverse base metal crack. By varying the width of the fingers, different degrees of severity of weld straining may be developed.

Finger tests of Type 347 heats involving welds of 8 and 11% ferrite showed that weld cracking was reduced but not eliminated by using high-ferrite electrodes for materials of unusually high nickel content (13.5 to 13.9% Ni).

Auto cracking tests to evaluate base metal cracking tendencies were conducted, consisting of fusion and electrode welds on $3 \times 6 \times 1$-in. sections. Coarse-grained material, oriented to produce cracks, was used. The fine-grained material tested was expected to be least susceptible.

The following conclusions were drawn from these tests:

1. Standard and low-carbon Type 304 show no tendency to develop base metal cracks.

2. Extensive base metal cracks occur in standard Type 347 where fusible grain boundaries are oriented perpendicular to the weld. Base metal cracking is not reduced by the use of ferrite-containing electrodes but the extension of these cracks into the weld metal is reduced 50% by using 8% ferrite electrodes.

3. Low-carbon, low-columbium Type 347 develops twice as many base metal cracks as standard 347

Weld Cracking . . .

when tested in coarse-grained oriented condition. Here again metal cracks are not reduced by using ferrite-containing electrodes but the extension of cracks into the weld metal is reduced 50%.

4. Low-carbon high-columbium Type 347 shows highest susceptibility to base metal cracks of the 347 group, but 8% ferrite electrodes greatly reduce crack extension into the weld.

Cracking During Heat Treatment — Tensile specimens with weld beads were cycled thermally while under loads approximating the high-temperature yield point. Two longitudinal weld beads 180° apart were made on each specimen using only fusion welding (no filler metal added). The specimens were loaded at room temperature and then heated at 150° F. per hr. to the holding temperature (1150, 1550 or 1750° F.), and cooled at 150° F. per hr.

The standard Type 347 and the low-carbon high-columbium 347 which showed a tendency to develop auto-cracks when tested at 1750° F. gave low-ductility stress-rupture fractures. At low stresses there was no damage. This suggests that cracks visible after heat treatment originate from flaws in the weld region and propagate by a stress-rupture mechanism which requires near-yield-point residual stresses in the weldment. The microscopic size of cracks in the as-welded condition explains why they are not detected by normal methods of inspection.

The low-carbon high-columbium tested at 1150 and 1550° F. showed fewer low-ductility fractures at 1550° F. than at 1750° F. and none at 1150° F. Thus, the mechanism responsible for the development of low-ductility ruptures was more operative at 1550° F. than at 1750° F. Furthermore, prior testing at 1150° F. did not prevent them when testing again at 1550° F.

Similarly, low-carbon low-columbium Type 347 and standard Type 304 were tested at 1550° F. In the absence of microscopic notch-extension cracks, low-ductility fractures were not obtained with standard Type 304. For Type 347, low-ductility ruptures were obtained at near-yield-point loadings in the presence of microscopic notch-extension cracks.

Conclusions

1. Crack development after welding is related to the same factors that cause hot tearing in castings.

2. The more highly austenitic the base metal, the greater the ferrite content required to minimize weld cracking.

3. Additions of ferrite have no effect in preventing base metal hot cracking.

4. Base metal cracks are related to fusible grain-boundary segregates which are not identified.

5. Low-ductility ruptures are possible at 1550 and 1750° F. for material containing microscopic cracks when near-yield-point stresses are applied.

6. From production experience this result may occur in the range 1350 to 1850° F.

H. J. Nichols

XXII

This is the twenty-second of a series of advertisements dealing with basic facts about alloy steels. Though much of the information is elementary, we believe it will be of interest to many in this field, including men of broad experience who may find it useful to review fundamentals from time to time.

Normalizing Alloy Steels

There are several forms of heat-treatment commonly employed in the processing of alloy steels. Each in its own way modifies the mechanical properties and structures of steel, and each is chosen with a definite objective in mind. The five usual forms of treatment are normalizing, annealing, spheroidize-annealing, quenching and tempering, and stress-relieving.

In this particular discussion, let us consider briefly the purposes and effects of normalizing.

Normalizing is an operation in which the steel is heated to approximately 100 deg F above the upper transformation range, then cooled in still or agitated air. The basic purpose is to refine the prior structure produced by variations in finishing temperatures encountered in rolling or forging. The structure resulting from normalizing, being more uniform, will help create improved mechanical properties when the steel is subsequently reheated, liquid-quenched, and tempered.

There are times when large steel parts (heavy forgings, for example) cannot be liquid-quenched because of their size. In cases of this nature, the heat-treatment must consist of single or multiple normalizing followed by tempering.

High-temperature normalizing is sometimes used for grain-coarsening low-carbon alloy steels to promote machinability. (In high-temperature normalizing, steel is heated to more than 100 deg F above the upper transformation range.) At times it is possible to machine a steel in the air-cooled condition, the governing factor being the alloy content. However, the highly alloyed analyses may require annealing or tempering after normalizing, to decrease the hardness.

It is essential, when normalizing is employed, that free circulation of still or agitated air be provided. When air-cooling of individual bars or forgings is not practicable, the furnace charge should provide for some means of separation, such as racks or spacers.

If you would care to know more about normalizing, or any other phase of heat-treating, you are invited to consult with Bethlehem metallurgists. They have had long experience in such matters, and they know how each treating method affects the various alloy steels. They are always glad to give you any help you need.

And when next in the market, please remember that Bethlehem makes the full range of AISI standard alloy steels, as well as special-analysis steels and all carbon grades. We can furnish what you need.

If you would like reprints of this series of advertisements from No. I through No. XX, please write to us, addressing your request to Publications Department, Bethlehem Steel Company, Bethlehem, Pa. The first 20 subjects in the series are now available in a handy 36-page booklet, and we shall be glad to send you a free copy.

BETHLEHEM STEEL COMPANY
BETHLEHEM, PA.

On the Pacific Coast Bethlehem products are sold by Bethlehem Pacific Coast Steel Corporation. *Export Distributor:* Bethlehem Steel Export Corporation

BETHLEHEM STEEL

BETHLEHEM STEEL

Strand Annealers

30-KW Drever 12 tube furnace with 9 foot heating chamber. Capacity 85 lbs./hour (.020" wire); speed 50 to 200 feet per minute.

FOR

Bright Annealing

STAINLESS WIRE

Clean Bright high quality stainless or alloy wire is heat treated economically in Drever Continuous Bright Annealing Furnaces.

Versatility of production is possible by design of pay-off and recoiling mechanisms. Each block is driven individually, thus wire of different diameters may be annealed at varying speeds at the same time.

Proper atmosphere equipment is supplied depending on type of wire to be bright annealed.

Write for further details on this or other type of Drever Furnaces.

DREVER COMPANY

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SODIUM hydride descaling

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Fast, versatile, money-saving, the sodium hydride process descales a wide range of metals and alloys . . . pipes, bars, sheets, wires, molds. And does it smoothly and precisely throughout every operation.

Sodium hydride acts uniformly on high spots and crevices alike, yet never attacks base metal. No waste disposal problems, no pitting or loss of metal. Equipment is compact, low in cost, easily maintained.

Like to test this modern, highly efficient descaling method? We'll be glad to send you descriptive literature or, if you prefer, one of our Chemical Engineers will call to discuss your needs first hand. Just mail the coupon below, indicating your choice.

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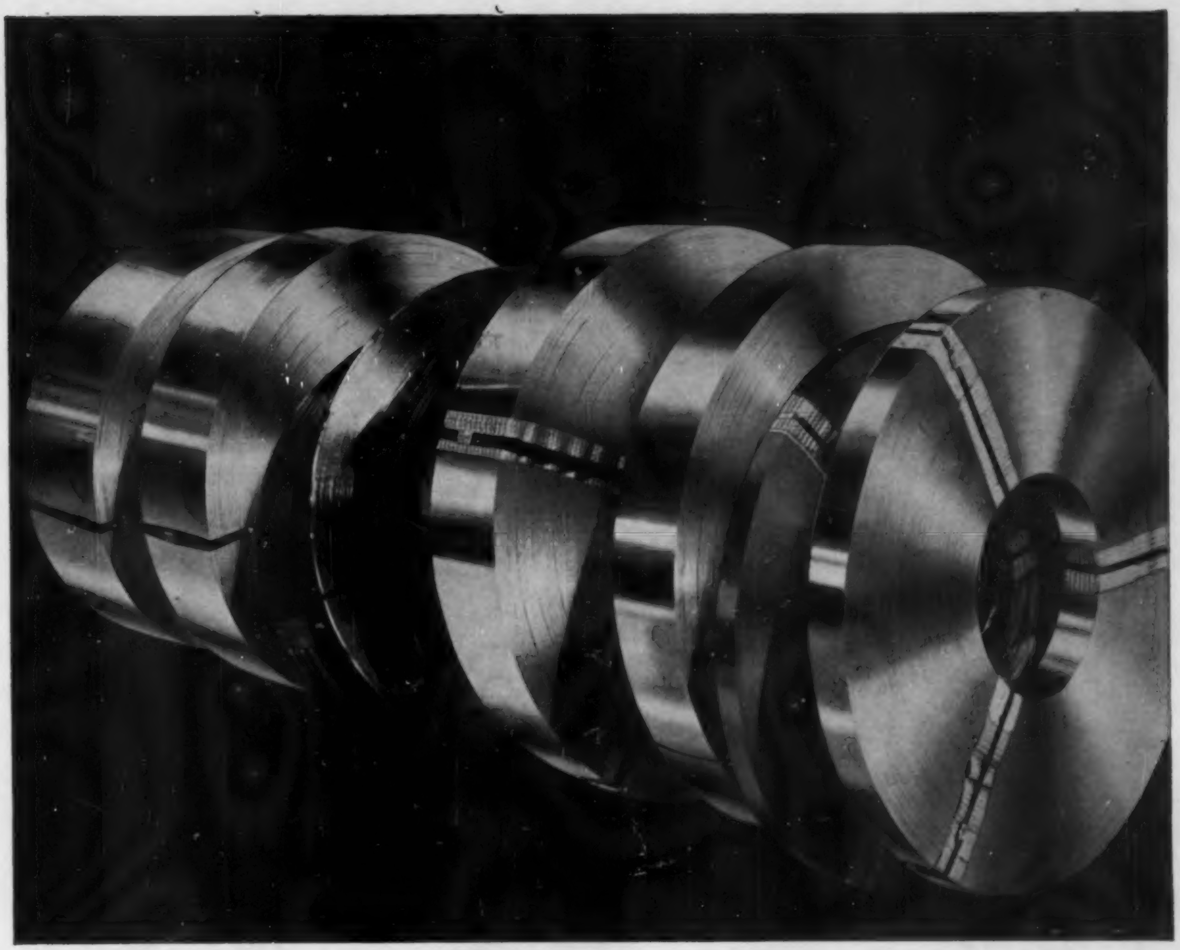

it's CRUCIBLE for the widest assortment of cold rolled specialty steels

Crucible has the largest assortment of cold rolled specialty steels you'll find anywhere. And delivery is dependable—in the size, grade, gauge, or analysis you want.

What's more, Crucible's steelmaking experience—its improved mill facilities—combine to bring you cold rolled steels of optimum uniformity . . . finer finish . . . better edges . . . flatter strip.

No need to shop around—call Crucible for carbon spring steel, alloy strip steel, or *any* ferrous analysis that can be cold rolled. For more information, write now for your copy of the 32-page booklet, "Cold Rolled Specialty Steels". *Crucible Steel Company of America, The Oliver Building, Mellon Square, Pittsburgh 22, Pa.*

CRUCIBLE first name in special purpose steels

Crucible Steel Company of America

...A Notable Coincidence

The Second World Metallurgical Congress

FLASH! Grand Prize will be the "Francis F. Lucas Award for Excellence in Metallography" Valued at $500.00 and Endowed by Adolph E. Buehler

RULES FOR ENTRANTS

Exhibitors do not need to be members of the American Society for Metals.

Work which has appeared in previous metallographic exhibits held by the American Society for Metals is unacceptable.

Photographic prints should be mounted on stiff cardboard; maximum dimensions 14 by 18 in. (35 by 45 cm.). Heavy solid frames are unacceptable.

Entries should carry a label on the back of the mount giving:

Classification of entry.

Material, etchant, magnification.

Any special information as desired.

The name, company affiliation and postal address of the exhibitor should be placed on the back of the mount.

Entrants living outside the U. S. A. should send their micros by first-class letter mail endorsed "Photo for Exhibition—May be Opened for Customs Inspection".

Exhibits must be delivered before Oct. 15, 1957, either by prepaid express, registered parcel post or first-class letter mail, addressed:

Metallographic Exhibit
American Society for Metals
7301 Euclid Ave.
Cleveland 3, Ohio, U.S.A.

Entries Will Be Expected From All Over the World— —Display Your Best Work

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(Optical and Electron)

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Class 2. Stainless steels and heat resisting alloys.

Class 3. Aluminum, magnesium, beryllium, titanium and their alloys.

Class 4. Copper, nickel, zinc, lead and their alloys.

Class 5. Uranium, plutonium, thorium, zirconium and reactor fuel and control elements.

Class 6. Metals and alloys not otherwise classified.

Class 7. Series showing transitions or changes during processing.

Class 8. Welds and other joining methods.

Class 9. Surface coatings and surface phenomena.

Class 10. Results by unconventional techniques (other than electron micrographs).

Class 11. Slags, inclusions, refractories, cermets and aggregates.

Class 12. Color prints in any of the above classes. (No transparencies accepted.)

AWARDS AND OTHER INFORMATION

A committee of judges will be appointed by the Metal Congress management which will award a First Prize (a medal and blue ribbon) to the best in each classification. Honorable Mentions will also be awarded (with appropriate medals) to other photographs which, in the opinion of the judges, closely approach the winner in excellence. A Grand Prize, in the form of an engrossed certificate and a money award of $100, will also be awarded the exhibitor whose work is judged best in the show, and his exhibit shall become the property of the American Society for Metals for preservation and display in the Society's national headquarters in Cleveland.

All photographs may be retained by the Society for one year and placed in a traveling exhibit to the various Chapters. They will be returned to the owners in May 1958 if so desired.

The Twelfth Metallographic Exhibit

Chicago, Illinois, November 2 to 8, 1957

Do heating coils in your vapor degreaser often get gummed up like this? You may be using a degreasing solvent that's poorly stabilized. Read below how you can minimize this coil-cleaning job, and degrease more parts between cleanouts.

Why Nialk® TRICHLOROethylene with psp gives you more degreasing, less downtime

Cut your degreasing costs with this permanently stabilized solvent

It's the *stabilizer* in the trichlorethylene that determines how long you can use it safely and efficiently.

Light, heat, air, acids, and active metals such as aluminum, given time, can break down improperly stabilized trichlorethylene, making it unfit for further degreasing.

Only Nialk TRICHLOROethylene has psp

The stabilizer in NIALK TRICHLOROethylene has **psp**—permanent STAYING power. It's neutral, non-alkaline. You *never* have to replenish it.

Only NIALK has this *permanent staying power*. Even after repeated distillations, its unique stabilizer prevents acid formation and other causes of breakdown.

NIALK works equally well with *all* metals.

psp means cheaper degreasing—here's why

You don't have to clean out your degreaser nearly so often with NIALK TRICHLOROethylene. You can degrease many more parts between cleanouts.

The NIALK stabilizer actively retards formation of degradation products in your degreaser. Cleanouts are easier, faster.

Get proof of Nialk's cheaper, safer cleaning

See for yourself how NIALK TRICHLOROethylene with **psp** stays stable, keeps cleaning efficiently long after other solvents have lost their punch. Write on your business letterhead for a revealing resumé of comparative metallurgical tests on five leading brands.

HOOKER CHEMICALS PLASTICS

6-1609

HOOKER ELECTROCHEMICAL COMPANY
408 UNION STREET, NIAGARA FALLS, N. Y.

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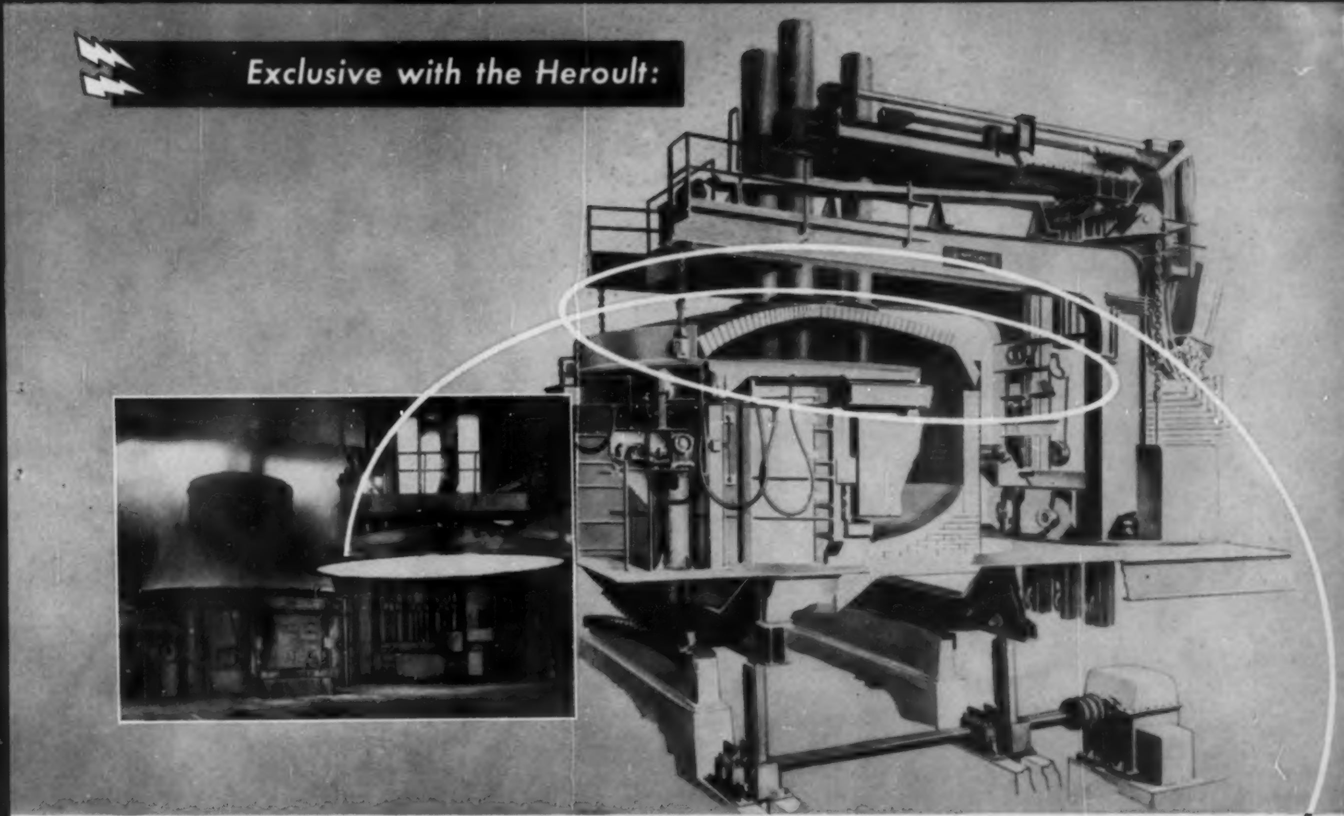
Manufacturers of VIRGO® DESCALING SALT, VIRGO ELECTROLYTIC SALT, VIRGO MOLTEN CLEANER



Water-cooled Skew Back Roof Ring

One of the features of the new Heroult is its low-cost maintenance. It is designed to make bricking easy and economical. Even the repair of the removable roof can be accomplished in much less time and with less labor and material cost. For the Heroult is the only electric furnace on the market with a water-cooled, skew-back type of roof ring. This patented design feature eliminates the need of special skew-shaped brick.

Embodying the latest in mechanical and electrical equipment, these widely used furnaces are noted for efficient performance and low operating and maintenance costs.

They are available in size of shell diameter ranging from 7′0″ up to 24′6″, and with rated charge capacity of from 8000 lbs. up to 400,000 lbs. They are equipped with removable roofs to permit top charging. Both gantry and swing-type roof-removing mechanisms are available. Door-charging furnaces and furnaces of special design, including units equipped with non-magnetic steel bottoms to permit induction stirring, can be supplied.

We welcome an opportunity to help you select and install the Heroult best suited to your needs.

The Heroult is the only 100% mechanically operated electric furnace

All of the movements of the Heroult are handled by motor-driven gear mechanism. This is a very important advantage, for it eliminates many maintenance difficulties. Your own maintenance man can easily keep this modern electric furnace performing efficiently with a minimum of service.

This and other Heroult exclusives, such as cage-type shell construction, independently supported operating mechanism, and water-cooled skew-back roof ring, make the Heroult the finest electric melting furnace on the market.

Ask for latest catalogue

This free catalogue will help you determine how Heroult Electric Furnaces can improve your operation . . . and enable you to make better quality steels. Tells you where and when an electric furnace is desirable. Gives furnace types, sizes, capacities and ratings. For your free copy, just contact the office nearest you, or write direct to Pittsburgh.

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UNITED STATES STEEL

MOLY NEWS

CLIMAX MOLYBDENUM COMPANY, 500 FIFTH AVENUE, NEW YORK 36, N. Y.

Super-Strength Structural Steels Boost Minimum Yield Strengths to 150,000 psi.

Seven steel companies in the U. S. are now producing a group of "Super-Strength Structural Steels" with considerably higher yield strengths than the well-known "High-Strength Low-Alloy" steels.

These Super-Strength steels offer minimum yield strengths ranging from 55,000 to 150,000 psi. And they have other useful properties, depending on composition, including strength at moderate temperatures, toughness at low temperatures, and good wear resistance. Almost all of these steels contain molybdenum as an essential element.

The search for steels with greater yield strengths has gone on for many years. Before about 1930, carbon steels with a yield point of roughly 30,000 psi were standard for almost all structural purposes. Then came the development of "High-Strength Low-Alloy" steels. They boosted minimum yields into the 50,000 psi range.

Now, the newer Super-Strength Structural Steels are being welcomed by designers, who see in them a way to solve one of their major problems — to minimize weight and size while retaining quality and reliability.

...For more information on these steels, including their trade names and compositions, circle number 1 on the coupon.

Moly's High Hot Strength Shows Promise for Jets and Rockets

Molybdenum-base alloys were described at the 1955 American Rocket Society annual meeting as having the greatest promise for true high-temperature operation.

Missile and powerplant designers are interested in moly mainly for its high temperature strength. Molybdenum-base alloys have been developed with higher useful strength at temperatures over 1600 F than any other presently known metallic material.

The jet propulsion field — including guided missiles and aircraft powered by rocket, ramjet, and turbojet engines — covers a tremendous variety of requirements and service conditions in respect to temperature, atmosphere, amount and type of stress, vibration, thermal shock, and prospective life. Molybdenum's properties make it a logical choice in many cases because it has:

1. High creep and rupture strength.
2. High tensile strength at high temperatures.
3. High modulus of elasticity.
4. A combination of high thermal conductivity, low specific heat, and low expansivity, which minimizes non-uniform temperature distribution and makes molybdenum insensitive to thermal shock.
5. High resistance to erosion by hot gases.
6. High melting point.

It seems safe to conclude that molybdenum-base alloys will become important structural materials in the jet propulsion field. And they will become essential for many parts operating at temperatures in excess of 1600 F.

...from "Molybdenum for High strength at High Temperatures," by R. Freeman and J. Briggs, JET PROPULSION, *February, 1957.*

For a copy of the complete article, circle number 2 on the coupon.

Moly Adds Strength and Corrosion Resistance to Titanium

Commercially pure titanium is fairly strong and highly corrosion-resistant. Alloying it, however, substantially increases these useful properties.

Molybdenum may prove to be one of the most useful of the alloying elements for titanium. Studies at Armour Research Foundation, for example, show that when molybdenum is used instead of vanadium, creep properties are greatly improved. At 1020 F, a stress of approximately 20,000 psi produces a creep rate of 10^{-4} in. per in. per hr in Ti-6 Al and Ti-6 Al-4 V, whereas 40,000 psi is required to produce the same creep rate in a Ti-7 Al-3 Mo alloy.

In summary, new alloy development is opening the way for titanium's extensive use in jet engines and air frames. Ti-Al-Mo alloys, for example, give better elevated temperature properties than the Ti-6 Al-4 V alloy now most widely used. And the alloy containing 7% Al and 3% Mo appears particularly promising.

Another Ti-Mo alloy contains 30 to 40% Mo. This alloy is claimed to resist boiling 40% sulphuric acid and boiling 20% hydrochloric acid as well as platinum, tantalum or gold. Such a retained beta alloy is weldable and could be fabricated into sheet. These corrosion-resistant characteristics would add to the value of all-beta Ti-Mo alloys.

...from "Molybdenum as an Alloy Addition for Titanium," by Harold Margolin, METAL PROGRESS, *February, 1957.*

For a copy of the complete article, circle number 3 on the coupon.

Moly Goes to Sea In A Sewer

Cast iron joint ring in pipe, before lowering into position. Joint rings were made by Alhambra Foundry Co., Ltd. and the concrete pipes poured by American Pipe and Construction Co.

Positioning 64 ton reinforced concrete sewer pipe sections puts quite a strain on the cast iron joint rings used to join them. Especially when the job is done under water at depths up to 210 feet.

Joint rings must be strong enough to withstand stresses developed when the pipe is drawn together, plus sufficient impact resistance to withstand handling and placement.

Those are good reasons why the County Sanitation District No. 2 of Los Angeles County specifies ASTM A 48, class 40 iron for the rings. In addition to the required 40,000 psi, tensile strength, and 2600 lb transverse strength minimum, (on a 1.2 in. test bar), the bar must be capable of deflecting at least 0.20 in. and the iron must contain at least 0.40% Cr, 0.60% Cu and 0.35% Mo.

Examination of pipe lengths after six years' service showed them in excellent condition. Equally good performance is expected from the most recent installations which extend some 8000 feet into the Pacific Ocean, and are believed to be among the largest in the country.

...For more information on the contribution of moly to toughness and shock resistance of cast iron, circle number 4 on the coupon.

Climax Molybdenum Company, Dept. 5,
500 Fifth Avenue, New York 36, N. Y.
I'd like more information on:
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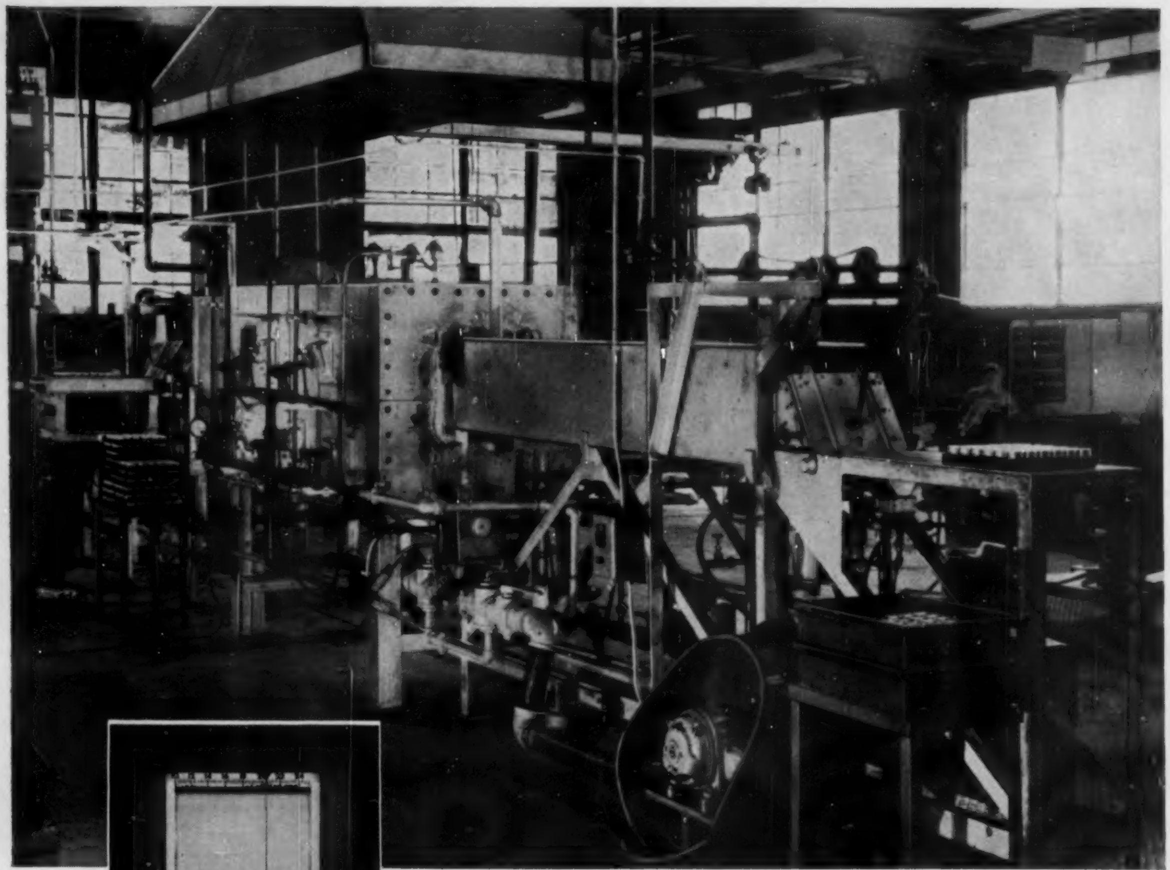
Name__________

Address__________

City__________



Speedomax® H . . . holds critical sintering temperatures in line at Burgess-Norton

Mix . . . press to a density between 6.2 and 6.6 gms/cc . . . and sinter under good conditions for fifteen minutes at temperature! That's the formula for quality sintered steel parts at Burgess-Norton where many millions of such parts—ranging from small bushings to 4" diameter gears—are turned out a year. Most of these parts are used "as sintered." Some may be further hardened, carburized or plated.

Good sintering conditions include a sintering furnace, like the Surface Combustion furnace shown, and straight-line control of the critical zone as provided by the Speedomax H controller above. An ammonia dissociator, also under L&N temperature control, provides the neutral atmosphere for the sintering furnace.

One of the most important determinations of the sintering process is temperature. If temperature is too high or too low, size and strength will be adversely affected. With Speedomax H 3-Action Position-Adjusting Type control, the sintering temperature is held well within critical limits . . . practically eliminating rejects due to improper sintering.

When installing your next heat treating furnace—whether it's electric or fuel-fired, continuous or batch—it'll pay you to investigate Speedomax H control. A phone call or letter to your nearest L&N office—or to 4927 Stenton Ave., Philadelphia 44, Pa.—will bring more information.

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PERECO continuous FURNACES

★ "sectionalized" factory built

In either "Sliding Plate" or "Car Type", Pereco factory-built sectionalized electric continuous furnaces are quickly assembled for volume production right on the job location—and just as quickly dismantled for moving or relocating. This new series of furnaces has silicon-carbide elements in three individually-controlled banks and provide accurately controlled operating temperatures of 500° F. to 2600° F. They're supplied complete with hydraulic pusher assembly and all temperature and power controls and are offered in a range of sizes and modifications to meet individual requirements.

★ easily assembled in the field
★ easily dismantled for moving

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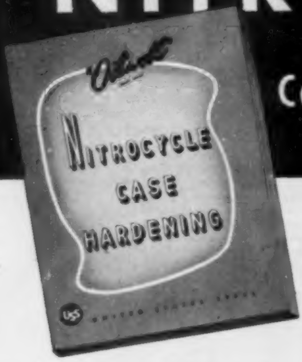

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For extreme case hardness where distortion from heat presents a critical work factor, the revolutionary new process that is explained in this handbook will greatly reduce finishing costs.

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Maximum operating temperature:
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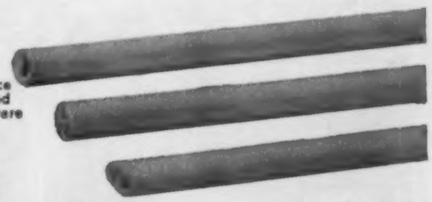
Triangle RR is a super refractory produced particularly to meet the challenge of the ever increasing high operating temperatures in industry. Its high purity in conjunction with its impervious structure of interlocking corundum crystals makes it very resistant to chemical attack.

Triangle RR pyrometer protection tubes and insulators are highly recommended for use with platinum, platinum-rhodium thermocouples where anyone of the following considerations is important:

1. **Greater accuracy over a longer period of time.**
2. **Freedom from attack of rare metals by silica or magnesia**
3. **Longer thermocouple wire life**
4. **When high rhodium content thermocouple wires are used**



Triangle RR Furnace tubes, crucibles and other laboratory ware are described in our catalog. Send for it today.

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